WACA

Final Report
April 1995

Historical Flow Regimes And Canyon Bottom Vegetation Dynamics At Walnut Canyon National Monument, Arizona

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Prepared for
Water Rights Branch, Water Resources Division,
National Park Service, Fort Collins, Colorado
Under National Park Service, Western Regional Office
Work Order No. CA-8026-8-0002

National Biological Service, P.O. Box 5614,
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ADDENDUM

Historical Flow Regimes And Canyon Bottom Vegetation Dynamics At Walnut Canyon National Monument, Arizona
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Rowlands, P.G., Avery, C.C., Brian, N.J. and H. Johnson

In the **Abstract** (page 1) – Estimates of annual runoff into Walnut Canyon, as predicted by our mass-balance calculations, suggests a reduction from 290,000 to 25,000 acre-feet due to the presence of the two reservoirs. The sentence should say "from 6,590 to 570 acre-feet". The numbers published were the total for a 44 year period, not an annual runoff.

In the **Conclusions** (page 79) - In the third paragraph, "Annual runoff into Walnut Canyon has been reduced from about 290,000 ac-ft to about 25,000 ac-ft due to the presence of a single reservoir" should be changed to read "from about 6,590 ac-ft to 570 ac-ft".

Addendum Prepared by Wm. R. Hansen on May 21, 1999.

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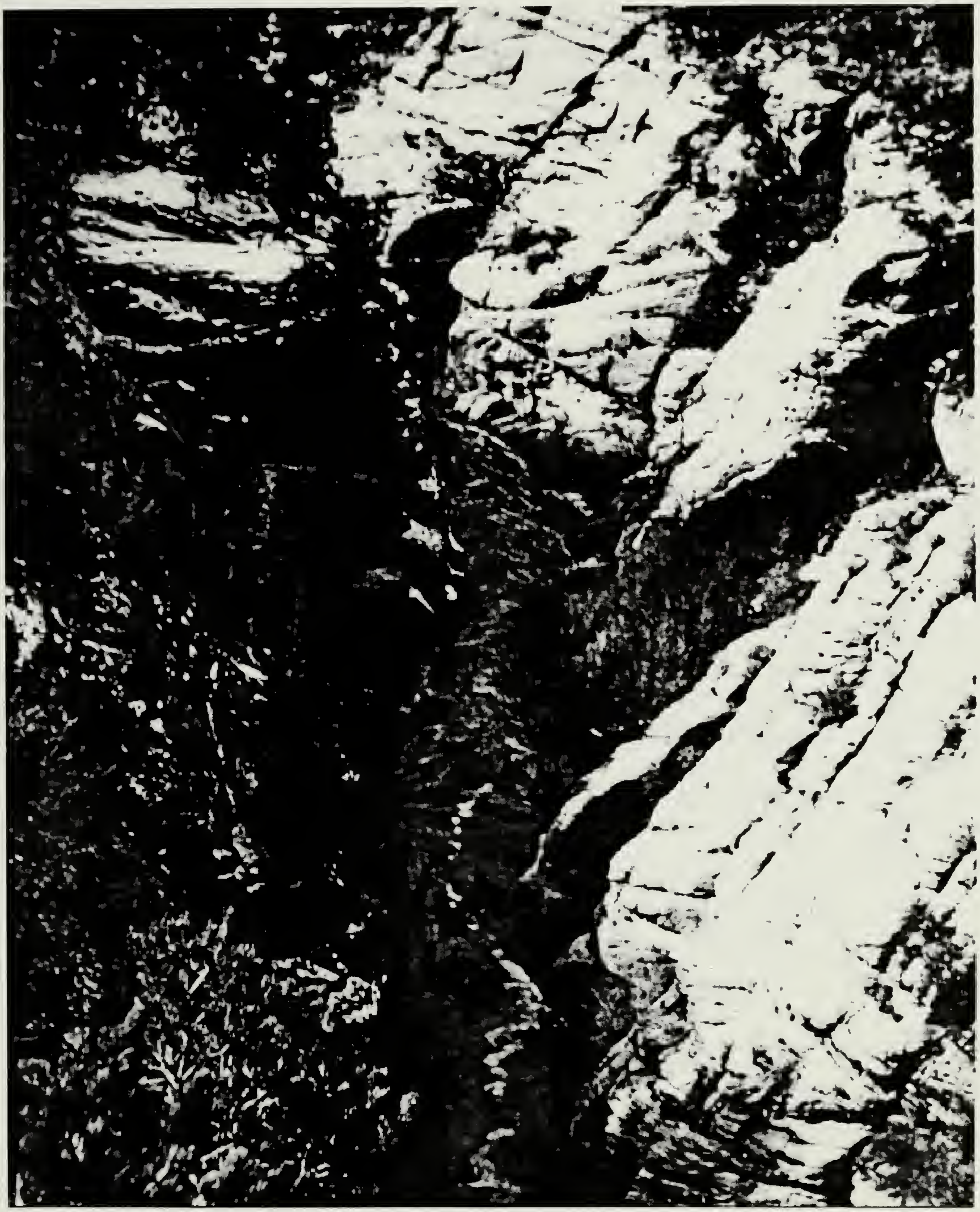

Flood waters through Walnut Canyon National Monument (February 1993), looking downstream along western edge of Island Trail.

HISTORICAL FLOW REGIMES AND CANYON BOTTOM VEGETATION DYNAMICS AT WALNUT CANYON NATIONAL MONUMENT, ARIZONA

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ABSTRACT

We investigated the impact that two, upstream reservoirs, Lower and Upper Lake Mary, built in 1904 and 1941, respectively, have had on the canyon bottom vegetation at Walnut Canyon National Monument. Anecdotal and photographic evidence suggest that Walnut Canyon was an ephemeral stream with an open, rocky bed maintained by seasonal flooding prior to 1904. Today, the channel is choked with dense stands of invading, disturbance adapted, upland woody species. The Walnut Canyon drainage is not gaged and long-term hydrological data exist only for Upper Lake Mary. Three scenarios were developed using a mass-balance approach. The scenarios suggest that the reservoirs have altered the frequency of flows in Walnut Canyon and have probably altered the magnitude and duration of the flood peaks. Winter-spring flow events through Walnut Canyon have been reduced from almost an annual event to one every nine years. Most reservoir spills occur in years with above-normal snow pack and during wet years when the reservoirs are full. Spills from Lower Lake Mary have varied in duration from three to ten weeks. Summer flows from the reservoirs have been completely eliminated through Walnut Canyon. Only unusually heavy local runoff from canyon slopes and tributaries below Lower Lake Mary creates any summer flow through the monument. Magnitude of flows through Walnut Canyon during these events has been variable, according to observations, but unquantified. Estimates of annual runoff into Walnut Canyon, as predicted by our mass-balance calculations, suggests a reduction from 290,000 to 25,000 acre-feet due to the presence of the two reservoirs. Dendrochronological analysis of ponderosa pine and Arizona walnut reveal changes in the mean ring index through time but no discernible changes can be attributed to dam construction. A 1973 vegetation survey of Walnut Canyon reported very similar plant species composition and cover as that seen in the canyon bottom today. After a fortuitous, eight-week spill in 1993, we remeasured eight, existing permanent monitoring plots, established in 1989, and compared plant species cover. Short-lived perennial and annual plant species not adapted to flooding and disturbance were physically eliminated, but have since recovered. Invading upland tree species, such as Rocky Mountain juniper, were removed from the channel proper, but seedlings and sprouts reestablished after the flood. Disturbance-adapted, upland woody species, such as New Mexico locust and Gambel oak, were actively resprouting. Boxelder and Arizona walnut appear to be slowly declining due to limited flood-induced reproduction. Comparisons of 1993 with 1989 plot data showed that the flood of 1993 brought about little overall change in plant species cover or composition. In contrast to Walnut Canyon, nearby undammed ephemeral drainages subject to twice-yearly seasonal runoff, maintain open channels and support obligate riparian plant species, such as willows. This suggests that a true riparian community with obligate riparian plant species may have been gradually eliminated from Walnut Canyon since 1904. The canyon bottom vegetation in Walnut Canyon appears to be in perpetual succession or transition. It is in dynamic equilibrium with post-dam, irregular spill events.

INTRODUCTION

The Water Rights Branch of the Water Resources Division, National Park Service, contracted with the Cooperative Park Studies Unit[1] to determine the historical flow regimes and canyon bottom vegetation dynamics at Walnut Canyon National Monument (WACA), Arizona. The prehistoric and historic flow regimes for Walnut Canyon as well as their effect upon the associated vegetation are not well documented or understood. Since the turn of the century, hydrologic conditions have changed due to construction of dams and other water diversions. Concomitantly, changes in riparian and aquatic habitat and composition have been on-going Brian (1992). This study endeavors to understand this complex hydrologic-vegetative system through field research, resurvey of past studies, and synthesis.

Objectives

This study proposed to evaluate and determine historic flow regimes and canyon bottom vegetation response as itemized by the following five objectives:

- To determine, to the extent possible, the pre- and post-dam flow regimes of Walnut Canyon, through a known time series of flow events.
- To determine if the construction of Lower Lake Mary Dam in 1904 and Upper Lake Mary Dam in 1940-41 captured flows historically flowing through WACA.
    - ✓ Has dam construction resulted in encroachment or elimination of canyon bottom vegetation and/or species/community changes?
    - ✓ Have the dams substantially altered the historic scene and ecosystem inhabited by the Sinagua Indians?
- To core tree species at the rim, slope, and canyon bottom of WACA, to correlate growth and scarring with drought, dam construction, and hydrologic and climatic records.
- To inventory and evaluate the existing canyon bottom vegetation at WACA.
- To inventory and evaluate nearby undammed drainages with similar riparian vegetation communities to determine how they differ from Walnut Canyon.

The following working hypothesis was employed as an initial guide and assumption: *There is no causal relationship between construction of the Upper and Lower Lake Mary Dams and the past or present canyon bottom vegetation dynamics at WACA.*

The term "riparian" is used in this report, but is generally restricted to citations of other authors' descriptions of the vegetation and physical factors (e.g., Bemer 1990, Phillips 1990, Jenkins et al. 1991, Brian 1992). A riparian area or ecosystem may be defined as a "terrestrial ecosystem characterized by hydric soils and plant species that are dependent on the water table (saturated zone) and/or capillary fringe" (U.S. Department of Agriculture, Forest Service 1989). Mitsch and Gosselink 1993 cite a number of definitions and descriptions of "riparian zone" or "riparian ecosystem". Most of these stress riparian zones or ecosystems as interfaces between aquatic (i.e.,

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[1] This office, now called the Colorado Plateau Research Station, was transferred from the National Park Service to the National Biological Service under the National Ecology Research Center (Fort Collins, Colorado) on November 11, 1993.

streams or rivers) and terrestrial communities. "In arid regions, riparian vegetation may be found along or in ephemeral streams as well as on the flood plains of ephemeral streams (Mitsch and Gosselink 1993)."

Kar and Schlosser (1978) and Swanson et al. (1982) provide reviews of the various definitions of riparian. Tiner (1984) states than in arid and semiarid regions of the western United States, lands that occupy the 100-year flood plain of streams and rivers are commonly referred to as riparian. The boundary of a riparian ecosystem is usually referred to as the stream-side or upland plant community where soil moisture is not a limiting factor for established perennials (Johnson and Lowe 1985). Hupp (1992) uses a more restrictive and hydrologically based definition of riparian in reference to channel banks and those areas subject to an annual hydroperiod.

In Walnut Canyon, there are few examples of obligate riparian plants or hydric soils. These are associated with isolated seeps. The cycle of water flow in Walnut Canyon is highly irregular and non-seasonal . In the strict sense of the term "riparian", there is no functional riparian ecosystem in the bottom of Walnut Canyon. We considered using terms such as "modified" or "altered" riparian to refer to the ecosystem and vegetation within and adjacent to the generally dry Walnut Canyon stream channel. Instead, we chose the more neutral term "canyon bottom" in reference to the existing ecosystem and vegetation. Joyce (1974) in describing the vegetation communities of Walnut Canyon, also chose the term "Canyon Bottom" with respect to this vegetation; "riparian" is noticeably absent from Joyce's paper.

Scope of Study

The scope of this study was limited to the effects of the Lake Mary reservoirs on the canyon bottom at WACA. No attempt was made to examine the effects of other local land uses, such as logging, grazing, land development and urbanization, and fire. Comparison canyon studies were limited to a 25 mile radius of Flagstaff so that geographic or geomorphologic variation would be minimized.

SETTING

Walnut Canyon National Monument

The Walnut Canyon drainage from Upper Lake Mary to Santa Fe Dam, including WACA, was the focal point of this research. WACA is located approximately 11 kilometers (km)[2] southeast of Flagstaff, Arizona, in Coconino County on the Colorado Plateau (Figure 1). WACA encompasses 909 hectares (ha) (Walnut Canyon National Monument 1976). Elevations range from 1,902 meters (m) at the bottom of the drainage on WACA's eastern boundary at Santa Fe

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[2] Throughout this report, we have used a single set of units of measurement. In the case of hydrological data, we have retained the U.S. Customary measurements since they are well established in the literature and in usage by U.S. Federal Government agencies. A conversion table for metric (SI) and U.S. customary (inch-pound) units is given in Appendix I.

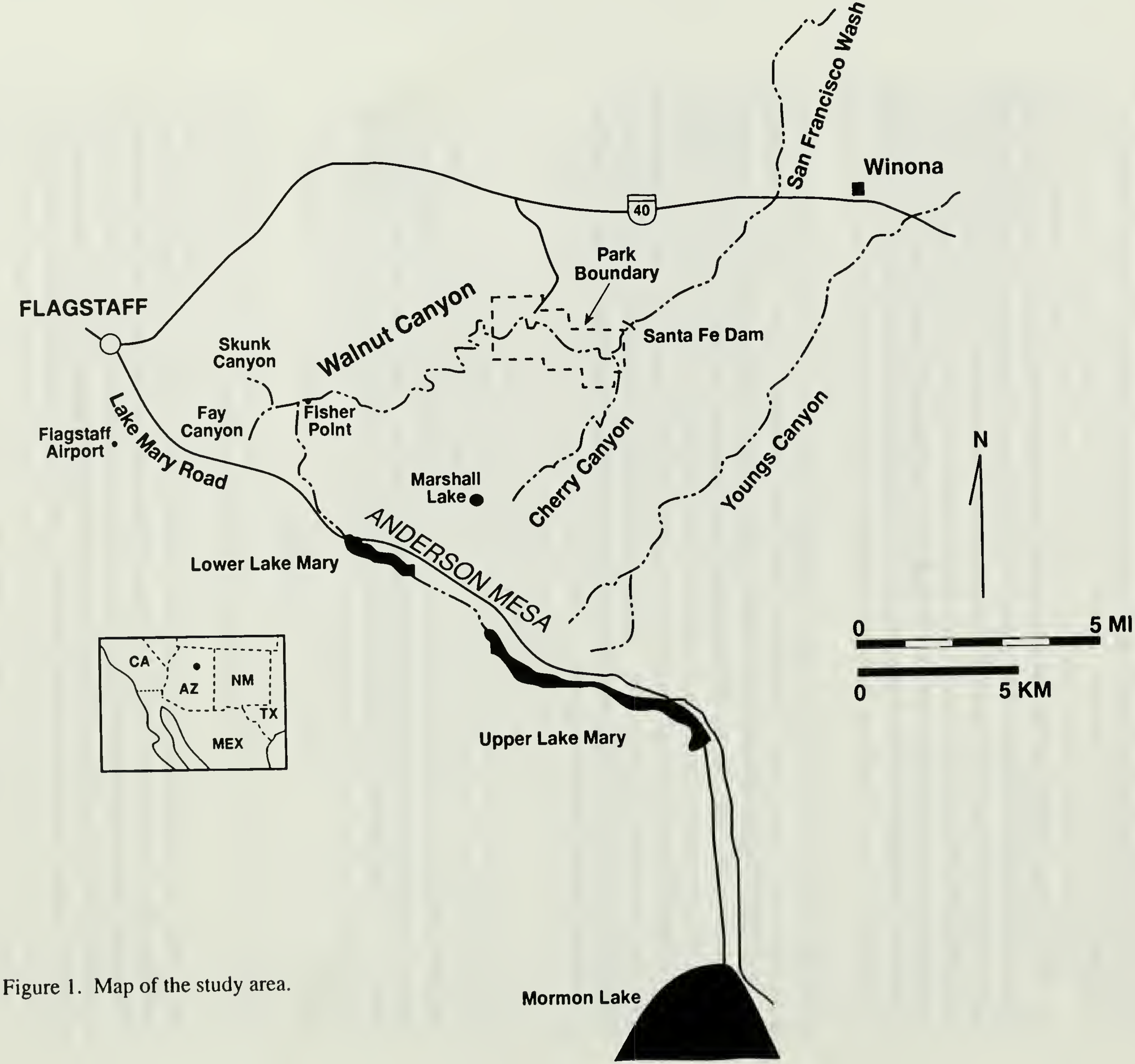

Figure 1. Map of the study area.

Dam to 2,040 m along the southwest corner at rim level. The depth of Walnut Canyon is seldom more than 120 m deep.

At the turn of the century, the area around WACA was part of the San Francisco Mountain Forest Reserve (Shimer and Shimer 1910), established in 1898 and administered by the Forest Service, U.S. Department of Agriculture. In 1906, President Theodore Roosevelt set aside 167 ha as a national monument (Colton 1932). Nine years later, on November 30, 1915, President Woodrow Wilson established WACA under the jurisdiction of the U.S. Department of the Interior, National Park Service (Colton 1932). The boundaries were subsequently enlarged on September 24, 1938, to 390 ha (including a 95 ha private inholding on the eastern boundary) by President Franklin D. Roosevelt (King 1941). In 1952, additional acreage, consisting of a 300 m strip of land along 4.8 km of land south from Interstate 40, was included by Executive Order for the purpose of constructing a paved approach road. Currently, local environmental groups are lobbying to extend the boundaries of WACA to include Sinaguan ruins now located on adjacent Forest Service land.

Climate

Weather records were obtained from WACA, the Flagstaff Airport, and published climatological records (Sellers and Hill 1974). Only precipitation is available for WACA and has been reported since 1951. The Flagstaff Airport weather record goes back to 1898 and includes precipitation and temperature. The area's climate, as described by the summarized data for the Flagstaff Airport (Figure 2), has vigorous cold winters, mild and pleasantly cool summers, moderate humidity, and considerable diurnal temperature change. The growing season is short with 153 days when the minimum temperature is above 32° Fahrenheit.

Precipitation

The yearly pattern of precipitation at both WACA and the Flagstaff airport, which differ in elevation by about 100 m, is very similar. The area is semiarid with about 503 millimeters (mm) of precipitation falling each year. The months of April, May and June are the driest, often with little or no recorded precipitation. The "bimodal" precipitation pattern typical of Arizona's monsoonal climate is evident with precipitation maxima in both winter and summer. Winter precipitation comes from Pacific frontal storms which are more or less widespread, with about 75% of the moisture falling as snow at these elevations. Winter snowfall accumulations vary. As little as 30 centimeters (cm) of snowfall has been recorded during mild winters whereas 250-500 cm have been recorded during severe winters. Summer precipitation is released from monsoonal, convectional cells which originate from the Gulf of Mexico. Occasionally, late summer and early fall tropical disturbances bring moist, warm air from the Gulf of California and the eastern Pacific. These tropical storms, or *chubascos,* often dissipate northeastward over the Southwest and bring widespread heavy rains and massive flooding (Sellers and Hill 1974, Webb and Betancourt 1992). In the Flagstaff area, about one-third of the precipitation (188 mm) falls in the summer months of July to September. Orographic influences of the San Francisco Peaks increases the amount of precipitation in the Flagstaff area relative to other stations of similar elevation. Due to its slightly

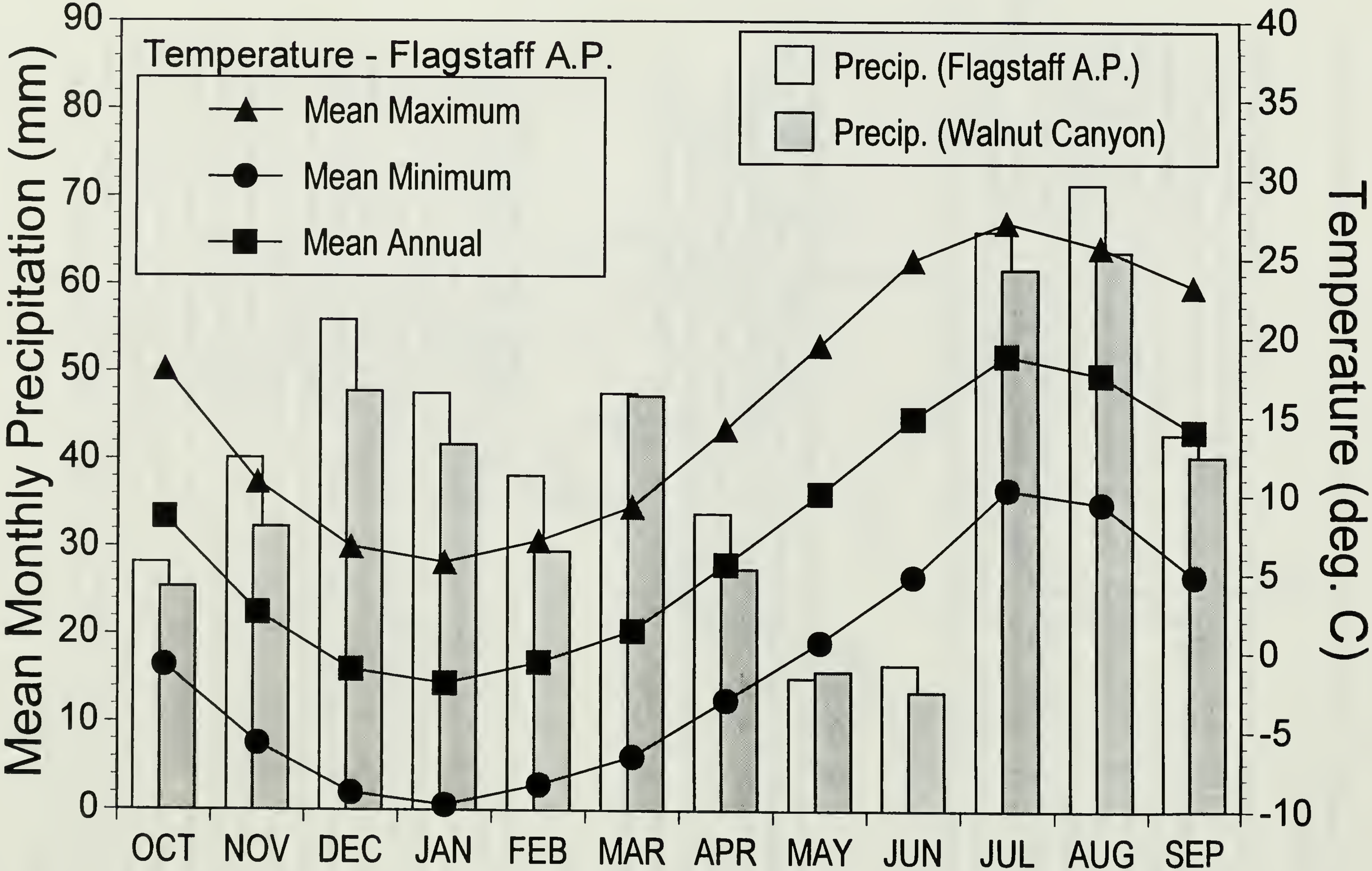

Figure 2 . Climatic summary for Flagstaff at Pullium Airport (1931-1972) with Walnut Canyon precipitation (1951- 1972) superimposed for comparison. Original data from Sellers and Hill (1974).

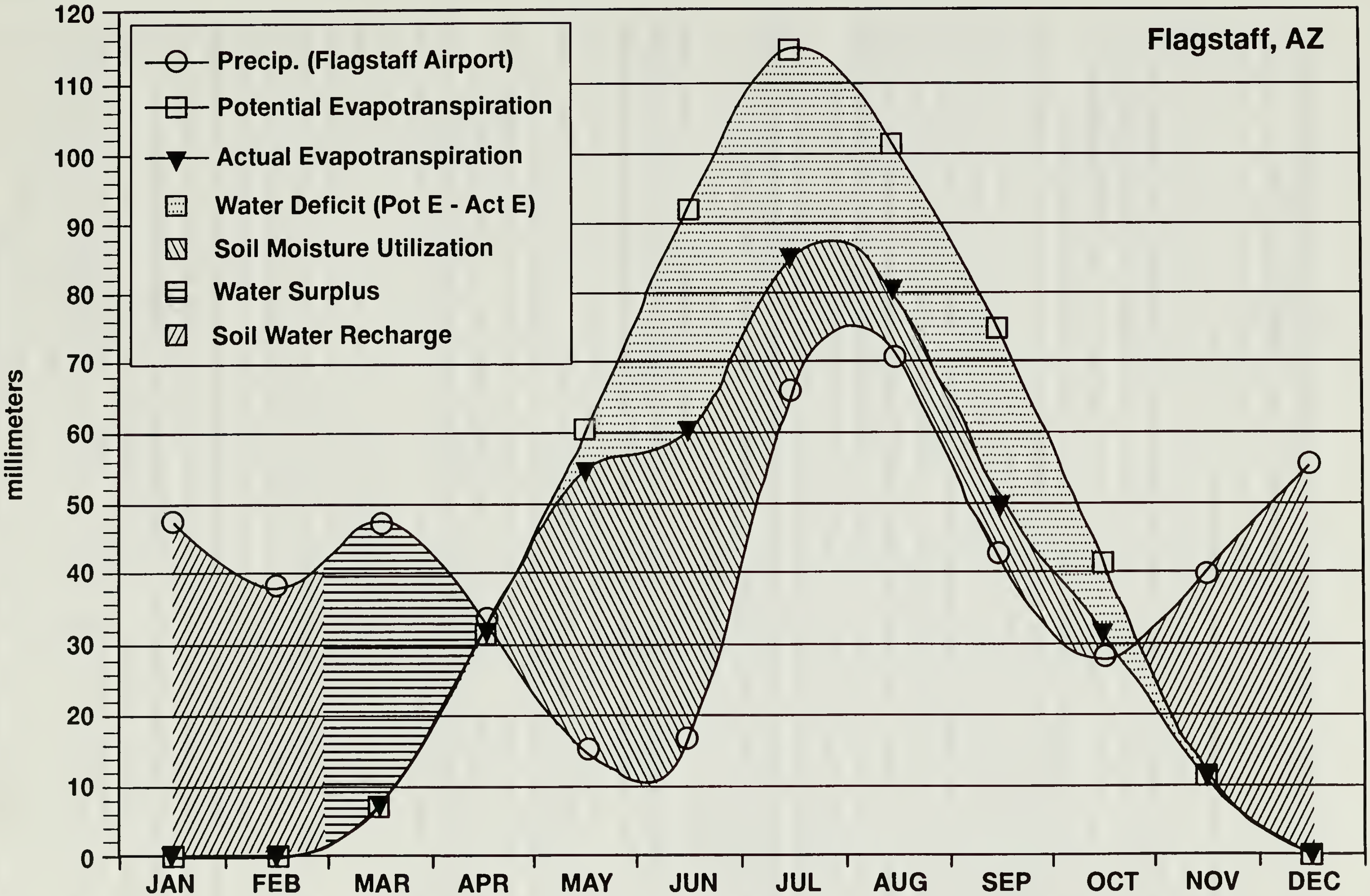

Figure 3. Water balance chart for Flagstaff airport, Arizona. Original data from Sellers and Hill (1974).

higher elevation, Flagstaff Airport's mean annual precipitation of 503 mm is slightly higher than WACA's 449 mm. This is true for every month of the year except May and June.

Temperature and Potential Evapotranspiration

The mean temperature in the Flagstaff area is approximately 37° Celsius (C) and ranges from -10°C in January to 27°C in July. The record extremes (between 1931 and 1974) are -30°C in January 1971 and 35.6°C in June 1970. Below zero temperatures have occurred as early as October 2 and as late as June 8 (Sellers and Hill 1974). Daily temperatures are variable, especially during the fall and winter months of October to March, as a result of extensive snow cover and clear skies.

Potential evapotranspiration as calculated by the Thornthwaite Method (Thornthwaite and Mather 1957) averages 537 mm per year[3] and the ratio of potential evapotranspiration to precipitation is 1.07, indicating a marginally semiarid climate, at least for the warmest part of the year. On the other hand, Eagleman (1976), using a different estimate of the water balance, gives a ratio of potential evapotranspiration to precipitation for Flagstaff of 1.67 and predicts no effective moisture surplus whatsoever for the entire year. Using the Thornthwaite Method, potential evapotranspiration exceeds precipitation in the months of May through October in spite of the relatively high summer precipitation. June is the driest month and the period of most intense water stress for the native vegetation.

The interrelation among the climatic elements is illustrated in a water balance chart for Flagstaff (Figure 3). The water balance model suggests that, in spite of the summer rainy season, a water deficit occurs from May through October. The deficit appears to ameliorate somewhat after July due to the monsoonal precipitation period. Nevertheless, this part of the year is a period of water utilization and ground water withdrawal by vegetation. A water surplus is predicted to occur only during the early spring months of March and April and coincides with the period of maximum runoff. Soil water recharge begins in November and continues through February. Predictions of meager runoff by the Thornthwaite method are corroborated by existing hydrological studies discussed below.

Geology

Several geological formations shown on Figure 4 (end pocket) have been recognized at WACA. Recent alluvial deposits as thick 23 m are present in stream channels and lake beds. Colluvial deposits are primarily found along the downthrown sides of faults, in canyons, and along margins of lava flows (Peacock 1978). Their thickness has been estimated to exceed 45 m (Harshbarger & Associates 1977). Lava flow and cinder deposits are common and cap Anderson Mesa and much of the Lake Mary watershed area. Within the Lake Mary Graben, the lava flows are approximately 38 m thick and are covered by Quaternary alluvium.

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[3] The Arizona Bureau of Mines has calculated the evapotranspiration for Flagstaff at an average value of 532.5 mm. This agrees closely with our estimate above. Harshbarger & Associates (1972) do not cite a reference, but their estimate, based on the description of the variables used in their methods section, was based on a mass balance model.

The Triassic Moenkopi Formation is the uppermost sedimentary rock unit and ranges in thickness from 0 to 120 m. This formation is present only in patchy outcrops along the upthrown side of the Anderson Mesa fault, in the Marshall Lake Graben, and in narrow grabens oblique to the Anderson Mesa fault in Walnut Canyon (Peacock 1978). There are also isolated Moenkopi Formation outcrops on the Anderson Mesa proper adjacent to drainages leading into Walnut Canyon. The most prominent sedimentary units within Walnut Canyon are the 111 m thick Permian Kaibab Formation and the underlying 225 m Coconino Sandstone (Harshbarger and Associates 1977).

Structurally, the area is dominated by faults of hydrological significance (Figure 4 [end pocket]). The Anderson Mesa Fault is the major fault and forms the southwest boundary of Anderson Mesa and the northeast boundary of Lake Mary Graben. This fault strikes northwest along the Upper and Lower Lake Mary before striking due north beyond the southern edge of Upper Lake Mary and the north-south trending part of Walnut Canyon (Peacock 1978). Approximately one mile south of Fisher Point, the fault exits Walnut Canyon, cuts across Anderson Mesa, and crosses the canyon below Fisher Point.

With a topographic displacement of 60 m, the Anderson Mesa Fault has the greatest displacement of any fault in the Lake Mary area (Peacock 1978), except where a narrow graben was formed south of Fisher Point which has a displacement of 120 m (Henkle 1976). Numerous small faults, which may postdate the Anderson Mesa Fault, strike parallel to it along the downthrown side and delineate the Lake Mary Graben. The Lake Mary Fault which is downthrown by 36 m (Peacock 1978) is the largest of these and lies approximately 600 m southwest of the Anderson Mesa Fault.

Hydrology

Drainage Area

Walnut Canyon at Santa Fe Dam drains approximately 328 km^2 of the Mormon Mountain watershed (Schuyler 1909, Bremer 1988). The watershed begins north of Mormon Lake in what was originally known as Clark Valley (Barnes 1935). Runoff first enters Upper Lake Mary, the capacity of which is 5.1 billion gallons (gal) or 15,623 acre-feet (ac-ft). Once full, excess water may spill into Lower Lake Mary, the capacity of which is 2.8 billion gal or 8,590 ac-ft. The difference in elevation between the top of the spillway of Lower Lake Mary Dam and the WACA boundary (Figures 4 [end pocket] and 5) is 132 m, over a 28 km distance.

From the lower reservoir, the dry creek bed curves around the southwestern edge of Anderson Mesa, turns east at Fisher Point, and zigzags through a deep canyon carved in the Permian deposits of the Kaibab Formation and Coconino Sandstone. Skunk Canyon, Fay Canyon, and Cherry Canyon, the three major tributaries to Walnut Canyon, are small, first and second order streams. The Walnut Canyon drainage ends at the confluence with San Francisco Wash, approximately 5 km north of Interstate 40 (U.S. Geological Survey 1968). The Walnut Canyon

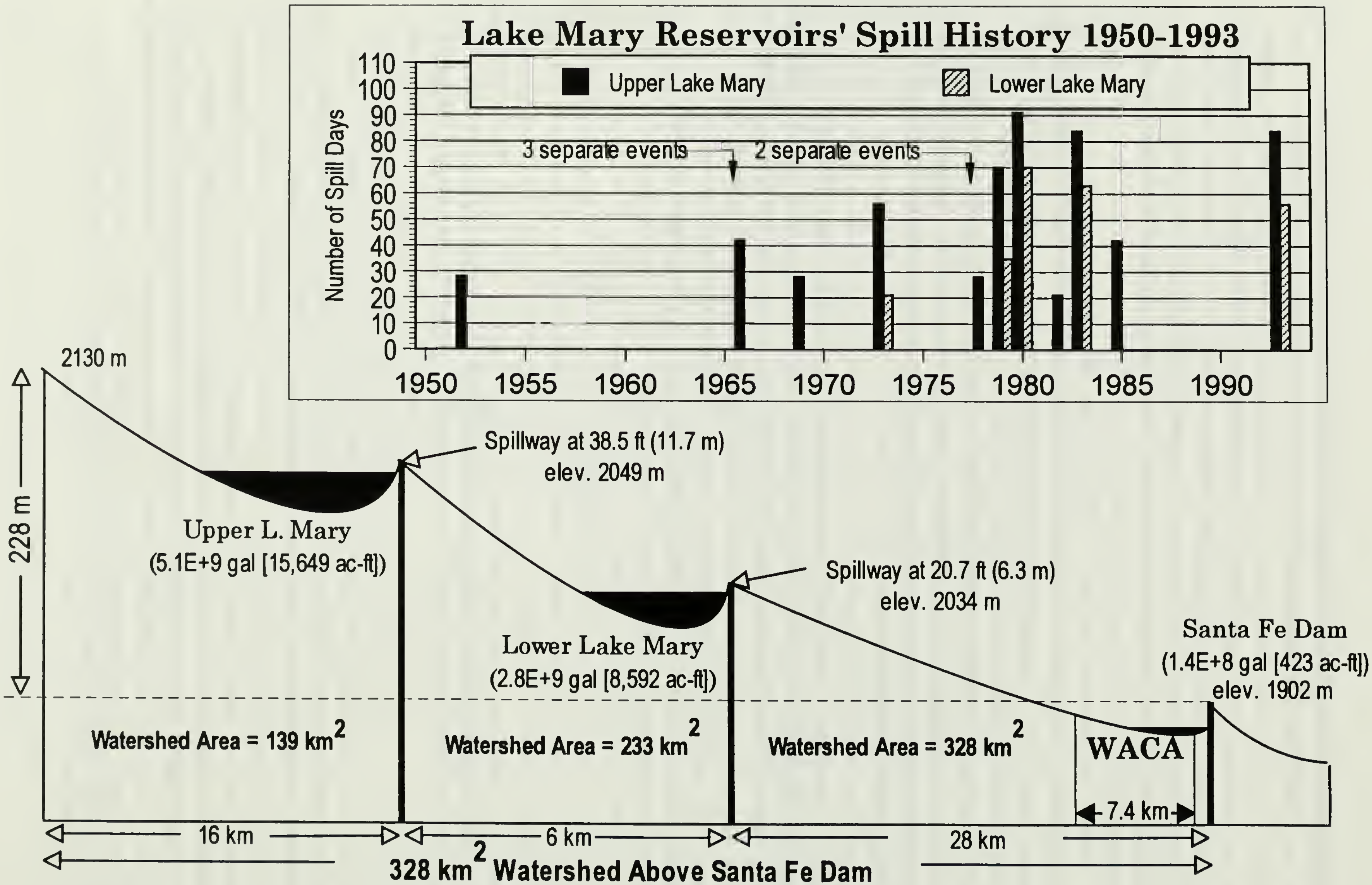

Figure 5 . Diagrammatic illustration (not to scale) of the Walnut Creek watershed from above Lake Mary Dam to Santa Fe Dam, below Walnut Canyon National Monument (WACA). The inset graph displays a summary of the spill record for Upper Lake Mary between October 7, 1950 and September 30, 1993 according to calendar years. Cross-hatched bars represent years (5) where Lower Lake Mary filled and spilled in turn.

watershed above San Francisco Wash is 364 km^2 (Harshbarger & Associates 1972). San Francisco Wash eventually joins Diablo Canyon, a tributary to the Little Colorado River.

Geohydrology

Walnut Canyon's morphology should be understood in terms of channel form and pattern. There is a close relationship between geologic structural features and drainage patterns (Henkle 1976). The incised meanders, i.e., those cut into bedrock, on the northern part of Walnut Canyon indicate rejuvenation of the creek due to the uplift of the Colorado Plateau (Henkle 1976). This situation is similar to that seen at Grand Canyon where rapid uplift forced the Colorado River to retain its "old" stream channel, while cutting down into the bedrock. The incised meanders at Walnut Canyon were cut by the original stream bed configuration prior to uplift and remained in their original orientation after uplift. Henkle (1976) suggested that the examinations of the sharp, angular turns in the Walnut Canyon stream course and joint orientations in the walls of the canyon indicate the marked influence of structural control.

Tectonic disturbances have created numerous joints and fractures. Sinkholes and other expressions of solution activity are common along such fractures. Joint orientations in the Walnut Canyon area are probably inherited from the large north-south trending faults, some of which are presently active (Henkle 1976). Highly fractured rocks in the vicinity of the major faults transmit 10 to 50 times as much water as do the same rocks when unfractured. In the Kaibab Formation, the joints and faults have been widened by solution activity. Numerous such solution features near the northwest end of Lower Lake Mary had to be dammed off because of the large quantities of lake water which were lost through them (Akers 1962).

Since both Upper and Lower Lake Mary are located in a graben, much of the water stored is lost to seepage through fault fractures. This problem becomes aggravated in high-flow years as seepage loss rates increase with storage depth and lake surface area (Harshbarger & Associates 1972, Blee 1988). Seepage occurs more rapidly in Lower Lake Mary. The seepage, however, recharges the local aquifer which lies in the Coconino Sandstone and the upper 45 m of the subsurface Supai Formation (Montgomery and Dewitt 1982) and provides water to the wells drilled by the City of Flagstaff.

Given the depth of the canyon, one might expect that the undammed Walnut Canyon would support a flowing stream. The geomorphology of Walnut Canyon is somewhat analogous to that of underfit rivers, whereby melting Pleistocene glaciers have carved channels that are much larger than would be created by the present flows (Malanson 1993). An underfit stream appears to be too small to have eroded the valley or canyon in which it flows, or a stream whose volume is greatly reduced. Underfit streams may be the result of drainage changes effected by capture, by glaciers, or by climatic variations. In the case of Walnut Canyon, the rate of downcutting was probably higher prior to the onset of the Holocene period when precipitation and runoff were higher than today (Reger and Batchelder 1971).

Table 1. Summary of the stream survey of three reaches along Walnut Canyon (Bemer 1990).

CHARACTERISTIC	REACH I	REACH II	REACH III
Valley configuration	Box-like	"V" Shape	"U" Shape
Floodplain width	13 meters	30.5 meters	37 meters
Rosgen type[1]	C2	C1	C3
Riparian area width	8.0 meters	30.5 meters	20 meters
Elevation range	1963 m to 1920 m	1920 m to 1914 m	1908 m to 1890 m
Riparian condition[2]	Good (3.5)	Poor (1.5)	Fair (2.0)
Sinuosity/Type	1.5/Well confined and moderately entrenched	1.4/Unconfined and moderately entrenched	1.2/Unconfined and moderately entrenched
Streambank composition:			
Bedrock	41%	10%	-
Large boulders	42%	-	-
Small boulders	2%	-	-
Gravel	-	-	45%
Silt	15%	45%	-
Sand	-	45%	55%
Channel bed composition:			
Large boulders	17%	-	-
Medium boulders	37%	-	-
Cobble	34%	-	11%
Silt	12%	50%	65%
Sand	-	45%	-
Gravel	-	5%	24%

[1] The Rosgen alphanumeric type (Rosgen 1985) is based upon the gradient, sinuosity, width to depth ratio, channel entrenchment or valley confinement, and landform feature of the soils or their stability.

[2] Riparian condition was evaluated on the basis of vegetation ratings (tree overstory, shrub midstory, and understory) on a scale of 0-4 (0=very poor, 1=poor, 2=fair, 3=good, and 4=excellent). High scores indicate reaches with brush communities, stable banks, and good regeneration of desirable plant species, while low scores indicate reaches with meadow communities, unstable banks, and regeneration of undesirable plant species.

Surface Stream Flow

Surface stream flows in the study area fluctuate widely and most commonly occur during snow melt and monsoon summer storms. However, the high infiltration rate of the soil retards surface runoff, supplying little water to feeder streams during summer thunderstorms. Sudden melting of a high snow pack and ground saturation seem to be required to yield significant runoff. This is supported by data presented in a Harshbarger & Associates (1977) report to the City of Flagstaff, which states, "Runoff occurs only during times of abnormal precipitation. Stream flow moves in the channels over relatively short distances and then sinks into meadows in the park areas and/or into fractures and faults which permit rapid downward penetration....Inflows to Lake Mary are seasonally and annually irregular." The mean inflow between 1941 to 1971 at Upper Lake Mary was estimated at 9.2 cfs, or 7,770 ac-ft per year (Blee 1975, Harshbarger & Associates 1977) with a minimum of 0 and a maximum of 24.2 cfs, or 17,500 ac-ft per year (McGavock et al. 1986).

Geomorphic Characteristics

A stream area survey (Table 1) for three reaches equaling 28.3 km of Walnut Canyon (Bemer 1990) describes the canyon bottom. Reach I of the survey began about three km upstream of WACA's western boundary and extended downstream to Cherry Canyon. Reach II of the survey, which includes the portion within WACA, encompassed the canyon bottom from Cherry Canyon to Santa Fe Dam. Reach III began at Santa Fe Dam and extended downstream for an undisclosed distance. Overall, the canyon geomorphology and watershed can be characterized as box-like in the upper reaches and "U" shaped at the lower elevations. The floodplain width increases as one moves downstream from 13 to 37 m with steep side slopes and an average gradient of 1-1.5%.

The stream area survey agrees with results of canyon bottom profile transects taken in 11 reaches of WACA (Phillips 1990). This latter study showed that the average width of the canyon bottom varies from 8 to 97 m, with the width of the streambed ranging from 7 to greater than 27 m. Generally, the channel is narrowest at the western edge of WACA and widest at the eastern edge near Santa Fe Dam. The stream channel may be the width of the canyon, as in narrow sections in the western half, or between 1/4 to 1/3 the width of the canyon in the eastern half.

Seeps and Groundwater

An inventory of perennial seeps (Figure 6) was conducted by WACA volunteer staff during late April to July 1989.[4] Fifteen seeps, one with standing water, were located within the boundaries and one seep was located just outside WACA's western boundary. No springs were observed. The number of seeps is probably conservative as 1989 was a very dry year with little or no precipitation from April to June (National Oceanic and Atmospheric Administration 1989). Tom Ferrell (personal communications, 1994) stated that the size of the standing water for the seep

[4] The inventory was conducted by volunteers Don Tenquist and Caroline Jefferson McCormick under the direction of Tom Ferrell. The work was accomplished by walking the corridor and noting the presence of a seep. An unpublished base map showing the location of the seeps was the only product.

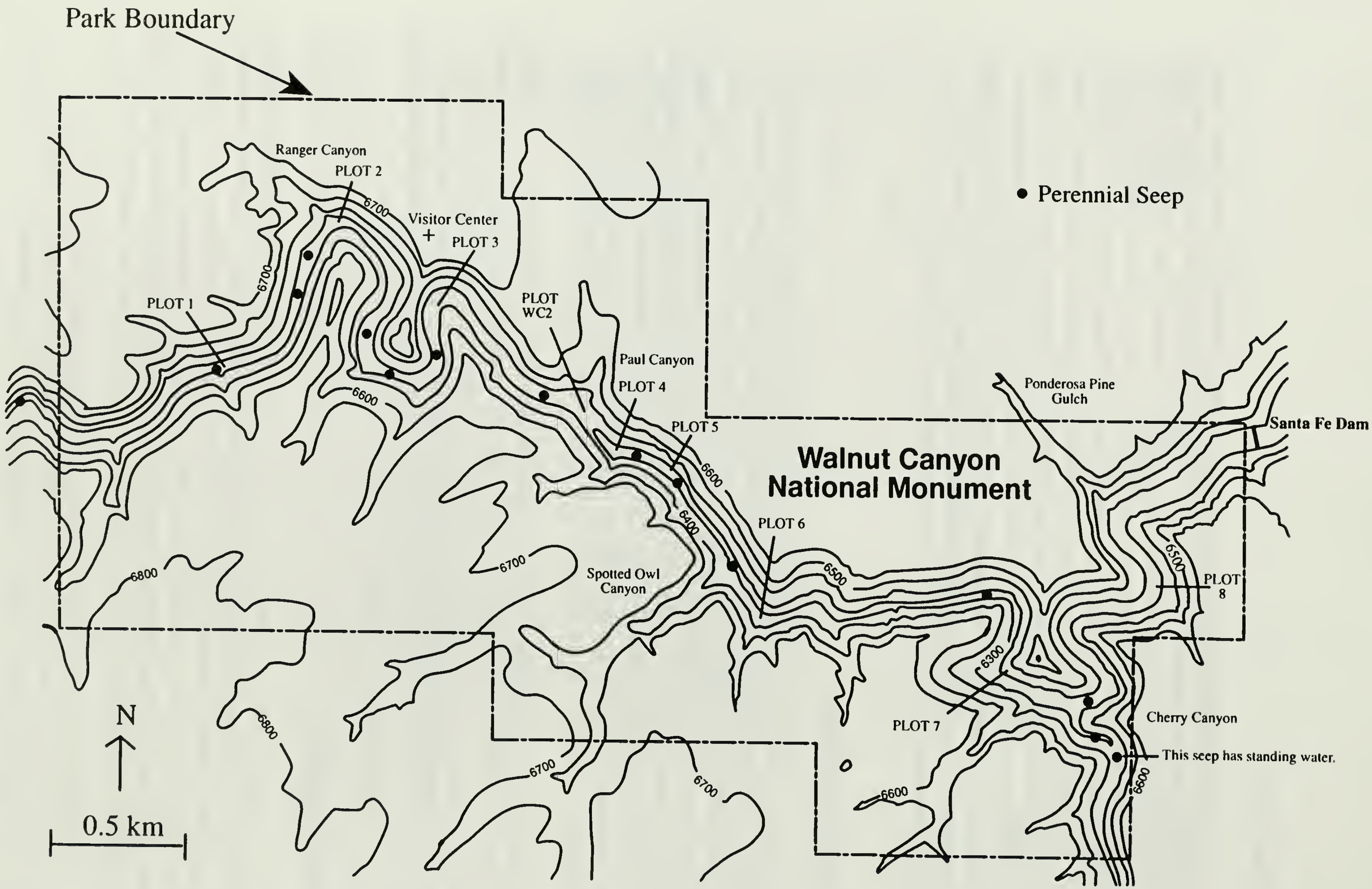

Figure 6. Location of canyon bottom seeps and vegetation plots in Walnut Canyon National Monument.

located above the junction of Cherry Canyon with Walnut Canyon was small, roughly about 0.1-0.2 m^2. The seeps in the canyon walls may derive from locally-recharged, minor groundwater systems and it is possible that they may be enhanced by the presence of the upstream reservoirs (National Park Service 1992).

The underlying Coconino aquifer which slopes from southwest to northeast supplies the groundwater at WACA (Harshbarger & Associates 1972). WACA's well, located near the visitor's center, is 602 m deep and produces at least 0.06 cfs (McGavock and Mann 1974). The aquifer level tracks the area precipitation closely and it is not thought that local drawdowns in the Lake Mary well fields have a long-term, significant effect on water levels at WACA (National Park Service 1992).

Historic Setting With Emphasis on Water Supply and Use

Natural Prehistory

Information on natural prehistory for WACA is scarce. There appear to be no published palynological studies focusing on the late Pleistocene or early Holocene times pertinent to the study area. Reger and Batchelder (1971) investigated freshwater mollusks in stream deposits in Walnut Canyon, near Winona, which radiocarbon dated at 11,000 years Before Present (BP). Based on stratigraphic evidence, they concluded that these mollusks inhabited a slow moving, perennial meandering stream. Underlying deposits indicate that prior to this time, the creek was a wide, shallow channel with a flow regime capable of moving gravel. The 11,000 year date coincides with the last ice-age (early Holocene) and glaciation of the San Francisco Mountains.

Information about the prehistoric vegetation at WACA is limited. However, a paleobotanical study has yielded several insights. Past and present vegetation was compared using eight woodrat or packrat (*Neotoma*) middens collected in Walnut Canyon (Murdock 1994). The middens were analyzed for composition and radiocarbon dated. Present vegetation was measured along 50 m transects placed directly in front of the midden location. The youngest midden, dated at 70 years BP, was collected at the bottom of the Cherry Canyon drainage within the WACA boundary, while the oldest midden, dated at 3,800 years BP, was collected at the rim of Fifth Fort located west of the boundary. The plant remains of the middens were compositionally and proportionally similar to the modern vegetation, except for the oldest midden, in which conifer needles were far more abundant. Douglas fir and pinyon pine trees may have been nearer to the midden site at that time or the woodrats may have traveled beyond the normal foraging distance of 30 m. Alternatively, pinyon near the oldest midden may have been depleted by the fuel and timber needs of the Sinagua Indians (Despain and Mosley 1990). The abundance of yucca, snakeweed, rabbitbrush, sage, and buckwheat has increased over time. Little to no yucca was found in the three oldest middens which dated between 3,430 and 3,800 years BP. Murdock (1994) postulates that the Sinagua Indians may have introduced, cultivated, and harvested yucca between 860 and 790 years ago.

Cultural Prehistory: The Sinaguan Scene

A subset of the second objective of this study is to determine if the upstream dams on Walnut Canyon have substantially altered the historic scene and ecosystem inhabited by the Sinagua Indians. *Sinagua* is a Spanish word meaning "without water." The following information serves as background information to describe what is known about this historic scene and ecosystem. A more detailed picture of the Sinaguan scene can be found in the recent report by Downum et al. (1995).

The history of human habitation[5] by the Sinagua Indian culture in Walnut Canyon began about A.D. 500. Continuous occupation continued through A.D. 1130, when WACA became an important community of 400-500 inhabitants. WACA is known foremost for over 87 prehistoric, cliff dwellings with a total of over 300 rooms located beneath sandstone overhangs in the canyon's upper slopes (Euler 1962, 1964; Gilman 1976; Baldwin and Bremer 1986; Stein 1986; Baldwin 1987; Bremer 1989; National Park Service 1992). About 180 surface archeological sites or ruins are also located on the north and south rims adjacent to the canyon. Dry farming in open meadows with a high cinder cover attracted an increasing number of people to the area, following the eruption of Sunset Crater in A.D. 1064. Schroeder (1977) suggested that following the eruption, groundwater accumulated and began to seep into drainages such as Walnut Canyon, probably converting previously dry or intermittent arroyos into flowing streams. The presence of bones of geese, ducks, and cranes indicates surface water became more readily available. Presumably the open water of these lakes or ponds, which would have occurred on the canyon rims, may have formed by tilting of the land or damming by lava flows. Moisture penetration in cinder is high (Schroeder 1977) and water is conserved by the cinder cover. Field structure ruins indicated that the north rim of WACA was the primary agricultural site with check dams and terraces (Bremer 1988). The canyon bottom itself offers few sites suitable for cultivation with the exception of the easternmost part near and beyond WACA's boundary.

There is some evidence of a gradual decline in occupation from about A.D. 1200, with final abandonment at the end of 1200's (U. S. Department of Interior 1985). Tree-ring analyses reveal that 23 years of drought, called the "Great Drought," occurred between A.D. 1276 to 1299 (Schroeder 1977, Dean et al. 1985). Pollen data from the Southwest show a decrease in arboreal pollen during this time (Weber 1981). Deficient precipitation, falling water tables, permanent water shortages, resource depletion, repeated crop failures, and rapidly expanding arroyo systems, are reasons most often cited as the probable causes of the abandonment of the area by the Sinagua Indians (Southwest Parks and Monuments Association 1971, Schroeder 1977). Deleterious environmental conditions prevailed until about A.D. 1475 (Dean et al. 1985).

Historical Record of Flow and Water Storage in the Walnut Canyon Drainage

A literature review of the hydrology of Walnut Canyon (Brian 1992) suggests that since the 1850's, flows in Walnut Canyon have been ephemeral[6]. Stream flow may have been perennial in

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[5] The earliest occupancy of Walnut Canyon has been dated to 4,000 years ago based upon split-twig figurines found in a cave site near WACA (Euler and Olson 1965).

[6] In the report, Brian (1992) used the term intermittent, but more accurately the term

the distant past when the Sinagua Indians inhabited the area, but in historical times, water has flowed only during snowmelt runoff after precipitation events. Prior to 1905, water from summer rains and severe winter snow flowed down Walnut Canyon for a few weeks each year. After 1905, water only entered Walnut Canyon when Lower Lake Mary overflowed. Brian concludes that after 1941, the amount of water flowing down the canyon declined and moisture in the basins and pools within WACA originates from runoff from the steep canyon walls and tributary drainages.

The lower Walnut Canyon drainage was first dammed between 1883 and 1886 with the construction of a masonry dam located at the downstream, eastern boundary of WACA (Shimer and Shimer 1910). The dam was called the Santa Fe Dam because it was built to impound water for the Santa Fe Railway. The years 1896 to 1904 saw a "long drought" in Arizona (Northern Arizona Leader 1970). In order to collect additional water, the dam height was raised in 1897, but overall, the dam was not successful. The reservoir filled for the first time in 1898, but the dam was not water tight and water in the reservoir lasted less than 200 days. In the summer of 1899, the dam collected no water at all. The railway discontinued use of the reservoir in 1904 (Arizona Heritage 1979). In 1934, stockmen from the Kellum Ranch dynamited the northern end of the dam to allow any water that had accumulated to leak out (Arizona Daily Sun 1979).

Repairs were made to the dam by the owner in 1990 and it briefly impounded runoff during March and April 1991 (National Park Service 1992) and again in 1993. The dam impounds some water after major flows, but the body of water is ephemeral. Alluvium washed down the canyon bottom by major flows collects behind the dam. The "reservoir" behind the Santa Fe dam is presently, almost completely filled with sediment (for example, see figure 15a).

The upper Walnut Canyon watershed was dammed by Timothy A. Riordan of the Arizona Lumber and Timber Company in 1900. Riordan built a test-dam across the narrow, lower end. He then sought and obtained a permit from the U.S. Department of the Interior to build a larger, permanent dam in 1904 (LaBoone 1981, Smith 1983). The land was set aside under federal statutes, it being specifically requiring that the area never be fenced or closed to public use and that livestock from nearby ranchers have access to the lake (Arizona Daily Star 1944). The earthen dam, completed in 1905 (Coconino Sun 1926), was 309 m long, 11.4 m high, and 29 m wide. The resultant 11 km long reservoir was named Lake Mary (later called Lower Lake Mary) for Timothy Riordan's oldest daughter. The reservoir first filled in March 1905. Lower Lake Mary, has been supplanted by Upper Lake Mary and currently does not contribute water to Flagstaff's water supply (Jack Rathjen, Lake Mary Water Treatment Plant, personal communication, 1994).

In November 1940, an additional earthen dam, measuring 267 m long, 11.1 m high, 4.3 m wide at the top, and 49 m wide at the bottom, was constructed above Lower Lake Mary reservoir. The spillway level was 7.95 m above the lake bottom. Completed in July 1941 and called Upper Lake Mary, this reservoir became an important aspect of Flagstaff's municipal water supply.

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ephemeral should have been used. Intermittent means that flow in a stream that comes and goes spatially (i.e., above to below ground), while ephemeral means flow is that comes and goes through time or seasonally (Malanson 1993).

When first built, Upper Lake Mary was 9 km long and stored 13,000 ac-ft, about 4 billion gal (Miller 1954).

Late in 1950, Upper Lake Mary Dam was raised 3.6 m, an increase of the dam height by 33 %, increasing the reservoir depth to 11.8 m (Miller 1954) and the total capacity to over 5.1 billion gal. The total, combined capacity of Upper and Lower Lake Mary reservoirs exceeds 7.9 billion gal (Jack Rathjen, Lake Mary Water Treatment Plant, personal communication, 1994). Mean annual inflow to the Surface Lake Mary area has been estimated at 7,770 ac-ft per year (Harshbarger & Associates 1977) or 69 mm per square mile of watershed area. The mean annual seepage from the Upper Lake Mary reservoir is about 3,190 ac-ft per year (Harshbarger & Associates 1977). Upper Lake Mary supplies between 50% and 75% of Flagstaff's water supply, the amount varying due to demand, surface water availability, ground water supplies, and other factors (Blee 1988, Jack Rathjen, Lake Mary Water Treatment Plant, personal communication, 1994) .

Biological Setting

Vegetation

The modern vegetation at WACA has been described by six floristic studies (Arnberger 1947; Spangle 1953; Joyce 1974, 1976; Phillips 1990; Jenkins et al. 1991). See the Vegetation Results section for a discussion of these studies. Fire occurrence studies at WACA were prepared by Despain and Mosley (1990) for the pinyon-juniper woodland and by Swetnam et al. (1990) for the ponderosa pine forest. Additionally, studies of vegetation on archaeological sites (Clark 1968) and the relationships between birds and plant communities (Haldeman and Clark 1969) have been done.

Five plant communities are found at WACA[7] (Jenkins et al. 1991, following Brown [1982] and Warren et al. [1982]): (1) a ponderosa pine forest on the canyon's rims covers the largest area followed by (2) a pinyon-juniper conifer woodland. Within the canyon are three associations: (3) the south facing slopes support a yucca-pinyon pine-blue grama woodland, (4) the north facing slopes support a Douglas fir-Gambel oak-muttongrass forest, and (5) a deciduous, riparian woodland of the canyon bottom. The later is split into two subassociations: (1) boxelder-wormwood-Arizona rose-New Mexico locust association and (2) boxelder-narrowleaf cottonwood.

A canyon bottom inventory of WACA (Phillips 1990) lists a total of 155 species[8] in 127 genera and 51 families from the canyon bottom based upon collections made in 1989 and herbarium records. The canyon bottom has the greatest diversity of species when compared to the other plant communities at WACA and contains over half of the species. Thirteen species, or 8% of the flora, are introduced or exotic plants, generally from Europe or Eurasia. Phillips created a baseline vegetation map and recognized eight vegetation associations, in addition to the "cliff"

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[7] See Appendix II for the scientific equivalent of the common names.

[8] Phillips (1990) cites 145 species from the riparian zone in the summary text, however we counted a total of 155 species listed in the annotated checklist.

category, along the canyon bottom. These include the mixed broadleaf, boxelder maple, narrowleaf cottonwood, ponderosa pine-mixed conifer, Gambel oak, mixed scrub, shrub-mixed grass, and annual disclimax associations. The "riparian" area in WACA (*sensu* Phillips 1990) has been estimated to be 31.25 ha.

Fauna

Faunal studies for WACA have identified a total of 119 bird species, with nine species having questionable occurrence (Greater 1935, Spangle and Spangle 1953, Haldeman and Clark 1969). A total of one amphibian, 12 reptile species (Salomonson 1973), and 31 mammal species are also listed (Hoffmeister and Carothers 1969; Salomonson 1973). Nineteen mammal species are noted as hypothetical and three have questionable occurrence.

METHODS

Geology

The geology of the Lake Mary reservoirs and Walnut Canyon area was investigated both through literature research and personal exploration. Geological formations and the primary fault system were verified in the field. While much of Walnut Canyon is difficult to access, most of the canyon was investigated on foot. Field orientation was established using the Flagstaff East and Winona, Arizona 7.5' topographic quads (U.S. Geological Survey 1962, 1968)

Hydrology

The first objective of this study was to determine, to the extent possible, the pre- and post-dam flow regimes of Walnut Canyon through a known time series of flow events. The second objective was to determine if construction of Lower Lake Mary Dam in 1904 and Upper Lake Mary Dam in 1940-41 captured flows historically flowing through WACA. Anecdotal information, literature reviews and data searches were conducted to determine pre- and post-dam flow regimes. Anecdotal information was systematically collected by interviewing a number of selected individuals including: past and present park rangers employed at WACA, City of Flagstaff Water Treatment Plant operators, and researchers who have worked previously on hydrological or ecological studies in Walnut Canyon or other local drainages.

History of water supplies and use was investigated by means of a literature search involving federal, state and local government reports deposited in local libraries as well as newspaper articles and journal entries dating back to the middle of the last century. The libraries visited included the Northern Arizona University Cline Library, Coconino County Public Library, The U.S. Geological Survey Field Office Library and Walnut Canyon National Monument Library. A search was also conducted for historic photographs taken from within the Walnut Canyon drainage. In addition to a search of the photographic data base housed at Walnut Canyon National Monument, queries were made both at the Smithsonian Institution (U.S. National Museum) and the National Archives in Washington D.C.

Availability of Stream Flow and Lake Stage Information

There are no gaged records of flow in WACA. However, the following three sources yielded hydrologic information. First, a partial record from a crest-stage station is available for Fay Canyon (No. 09400910), a tributary to Walnut Canyon located below Lower Lake Mary and above Fisher Point. Fay Canyon has a 7.2 km^2 drainage area (Hill et al. 1988). The station recorded only peak flows. Data was collected for 15 years between 1964 to 1980, with no record available for 1977 and 1978. Peak annual discharges ranged from 1 cfs (September 1975) to 87 cfs (December 1965). Peak discharge values of 8, 36, 66, and 98 cfs were computed for Fay Canyon for the recurrence intervals of 2, 5, 10, and 25 years respectively (Hill et al. 1988). It is noteworthy that Hill et al. (1988) report that basins in the Flagstaff area produce lower peak discharges than do similar-sized basins in most other parts of Arizona and that the annual peak discharge may occur at any time during the year. This conclusion is consistent with predictions of low runoff from the Thornthwaite and Eagleman water balance model which indicate a marginally semiarid climate. Because peak discharges per unit area in the Flagstaff area were extremely low and flood peaks infrequent, flood data collected at the nearest long-term gaging stations, such as the Little Colorado River or Oak Creek Canyon (in a different drainage), were not considered applicable to basins near Flagstaff (Hill et al. 1988).

Second, Blee (1988) conducted a study to determine evaporation and seepage losses at Upper Lake Mary. Over the period from 1969 to 1971, he used a continuous stage recorder to collect lake stage data at the upstream and downstream ends of the lake. The lower lake gage was permanent and the upper lake gage was temporary, operated only during May through October. The study showed that evaporation losses were 27% or 2,100 ac-ft per year during 1950-71 and seepage losses were 45% or 3,400 ac-ft per year over the same time period (Blee 1988).

Third, weekly water records for Upper Lake Mary have been collected from October 7, 1950 to September 30, 1993 by the City of Flagstaff. This information consists of 2,242 weekly records in the form of date, lake surface elevation, volume of water in the lake, and withdrawals for municipal use. A sample of this database is included as the first seven columns of Appendix III.

A measuring device (staff gage) was not installed at Lower Lake Mary Dam until the spring of 1959. Nineteen sixty, the first full year after installation, constitutes the beginning of the viable record for Lower Lake Mary. After the installation of the staff gage, measurements were made monthly until 1993 when weekly recordation began. Lower Lake Mary data, shown in the last column of Appendix III, consists of at least monthly depth records from May 4, 1959 to September 30, 1993 with weekly depth measurements taken during spills. This meager amount of data occurs because the reservoir, when it does contain water, serves as a recreation lake only and no water is withdrawn for municipal use. Until 1993, measurements were taken more as a matter of interest than the necessities of water management. No information is available to determine the rate of overflows from Lower Lake Mary.

Water records for the Upper and Lower Lake Mary Reservoirs were entered into spreadsheet data files. Data are missing for 286 weeks of surface water diversion from Upper Lake Mary and 18 weeks of stage (lake level) information when Upper Lake Mary ran dry in 1956.

Estimate of Reservoir Storage and Inflow into Walnut Canyon

In order to evaluate the impacts of dams on the frequency, duration and magnitude of flows on Walnut Canyon (objective 2), three "scenarios" were developed. Scenario one assumes that Upper and Lower Lake Mary Dams do not exist. Scenario two assumes that only Upper Lake Mary Dam is in place. Scenario three, assumes that Upper and Lower Lake Mary Dams are both in place. A scenario with only Lower Lake Mary was not considered due to the scarcity of lake stage and overflow data.

For all scenarios, contributions from tributaries below Lower Lake Mary were not considered. Inflows into Upper Lake Mary were estimated by adding seepage and surface diversions for Flagstaff to gross lake volumes. The lake levels were converted to storage volumes according to a nomograph available from the Water Treatment Plant. Seepage was determined by means of a stage-seepage loss relationship supplied by the Water Treatment Plant. No adjustments were made for loss of water due to evaporation because weekly or daily estimates for upper Lake Mary were not available and existing estimates for Upper Lake Mary were calculated only for a short period (Blee, 1988). The gross volumes for each week were subtracted from the previous week's total to determine the net change in reservoir volume. If the volume increased, inflow to Upper Lake Mary was assumed to have occurred. Inflow was transformed into cubic feet per week and acre-feet per week, and the daily average values were calculated as a seven day average inflow estimate. A sample of these data along with an explanation of the calculations are presented in Appendix III.

Inflow values were used to determine if overflow occurred and were separated into ≤50 cfs, 50-100 cfs, 100-150 cfs, 150-200 cfs and >200 cfs classes. Separation into discrete classes of inflow magnitudes and frequencies was possible by a simple database sort using the weekly estimates of inflow in descending order as the sort key. By resorting the database using the Upper Lake Mary Lake Levels as a secondary key, we get a database arranged in descending order by estimated mean weekly inflow and depth. A record with a maximum depth and an estimated mean weekly inflow greater than zero indicates a spill from Upper Lake Mary. The resulting data were used to generate information for the three scenarios and to estimate the number of weeks as well as years in which Upper Lake Mary Dam overflowed. Refer to Appendix III for a sample of the Upper Lake Mary database and example calculations.

Dendrochronology

The third objective of this study was to conduct tree coring of various tree species at WACA at the rim, slope and canyon bottom to correlate growth with drought, pre- and post-dam construction, and hydrologic and climatic records. We collected tree cores from 30 trees of five species as described below and used data from ponderosa pine trees cored by other studies. The preparation of dendrochronologies was subcontracted to the Tree-Ring Laboratory at the University of Arizona, Tucson. In addition, the cores were examined for scars caused by mechanical injury by rocks which may have been transported down the channel during high-flow events. The tree-ring chronology was compiled by Franco Biondi, whose status reports to the authors are available upon request. An existing long-term chronology based on Ponderosa pine

for the Walnut Canyon National Monument rim, kindly provided by the University of Arizona Laboratory of Tree-Ring Research (henceforth referred to as the WACA chronology), was used as a comparison check

Data Collection

Tree cores and some cross sections were extracted by the authors from several species of trees, within and closely adjacent to the boundaries of WACA using a Hagelof increment borer according to accepted collection methods (Stokes and Smiley 1968, Fritts 1976). Information on the location of the trees which were cored by this study, along with the cardinal direction of the core, aspect of the site, slope, stem diameter and circumference at breast height, height, crown type, associated species, relationship to other trees, associated species and site description is on file.

Tree-ring Index Calculation and Cross Dating the Increment Cores

The Tree-Ring chronology was obtained using the following equation:

$$\overline{I}_t = \frac{\sum_{i=1}^{n_t} \left(\frac{w}{y}\right)_{it}}{n_t}$$

Where:

$\overline{I}_t$ = average ring index at year t; w = ring width measurement;
y = intrinsic growth trend; n_t = number of specimens i that included year t.

Tree-ring growth typically slows down with age and must be detrended (Fritts, 1976). In order to maintain long-term growth trends over the last two centuries, the y term was quantified by a cubic spline with 1% variance reduction at a frequency of one cycle per 90 years (Cook and Peters 1981, Peters and Cook 1981, Holmes 1983). All statistical analyses were done using the original ring width index data. However, moving averages of tree-ring indices were calculated for graphical presentation.

Tree Species Considered

Ponderosa Pine

Seventeen ponderosa pine tree cores were collected from March to August, 1993. Cores R1-9 were collected from the rim and canyon slopes and cores R18-22 and R28-30 were collected from the bottom of Walnut Canyon. A few trees were cored twice yielding additional cores for study. Metal tags stamped with the R-number were attached to the bottom of all trees in order to relocate trees. All increment cores were glued to wooden mounts, sanded, and polished until the

smallest rings were clearly visible. Manual polishing began with 280-grit sand paper and continued with 400-grit and 500-grit sand paper. No increment core included the stem pith. Cross dating (Douglass 1941, Stokes and Smiley 1968) was ascertained by visually comparing ring patterns with the help of a binocular microscope. Ring widths were measured to the nearest 0.01 mm. Cores collected from other tree species were similarly treated.

Since this study focused on growth patterns before and after 1904, the periods 1800-1904 and 1904-1992 were of interest. In order to include those years, increment cores were measured from 1800 to 1992 whenever possible. Exceptions were R18 (undatable after 1900); R20 (whose innermost ring was 1874); R28 (whose innermost ring was 1834); and R30 (undatable after about 1950). Dating accuracy was numerically verified using the computer program COFECHA[9] (Holmes 1983), which identified no dating error.

Arizona Walnut

Eleven increment cores were collected in May and August 1993 from eight Arizona walnuts located in the bottom of Walnut Canyon. They were labeled R14-R16 and R23-27. Numerous other trees were cored, but the cores were discarded because of their rotten condition. R23 was cored three times and R26 was cored twice. The core from R14 did not include rings for 1962-64 because of an injury, and was therefore divided into two parts, A and B. Twelve cores were prepared. Arizona walnut is a diffuse-porous hardwood with fairly uniform vessel size from earlywood to latewood. After polishing, rings became visible under a binocular microscope using 10-30x zoom lenses. Ring boundaries were identified by a very narrow brown strip, darker than the rest of the ring, at the end of each annual growth increment. Ring boundaries were less visible toward the pith of each specimen, especially in R15, R16, R25, and R27. All cores were cross dated against one another and annual ring width measured to the nearest 0.01 mm.

Narrowleaf Cottonwood

Two increment cores were collected in July 1993 from one, large narrowleaf cottonwood, labeled R17, which was downed by the January 1993 high-flow. Neither core included the stem pith, and cross dating occurred from 1964 to 1993. Based on ring counts, the innermost ring of the longest core was 1956, which makes the tree at least 38 years old. Because of the limited time span covered by this tree, these two cores were not used in the final analysis.

Douglas Fir

Two increment cores were collected in August 1993 from one Douglas fir and labeled R31. This tree had been earlier tagged with a metal tag reading "#11." It is not known when or why this tree was tagged. Neither core included the stem pith and the inner part of one core was broken into several small pieces. Cross dating was only possible from 1900 to 1993. Based on ring

[9] COFECHA is not an acronym, but a Spanish word which means cross dating.

counts, the innermost ring of the solid core was 1710, which makes the tree at least 284 years old. Because of the lack of replication before 1900, these two cores were not used in the final analysis.

Boxelder

Six increment cores were collected in April 1993 from four boxelders and labeled R10-R13. Tree R13 was cored from one side of the stem all the way to the opposite site and tree R11 included several rings past the pith on the opposite side. Boxelder is a diffuse-porous hardwood with uniform vessel size from earlywood to latewood. Ring boundaries were identified by a very narrow brown strip, darker than the rest of the ring, at the end of each annual growth increment. Ring boundaries were less visible toward the pith of each specimen, and rings of tree R-10 were less visible over the entire length of the cord. All cores were cross-dated against one another. Tree R10 was 37 years of age and trees R11-R13 were 63, 66, and 65 years respectively. Although there were no locally absent rings and only one micro ring, year-to-year variation and inter-tree correlation of ring-widths were high. It was judged that double or triple the present sample would be necessary in order to produce a reliable tree-ring chronology with the ponderosa pine chronology for the same area (Franco Biondi, personal communication, 1994). This would minimize the likelihood of ring widths being in synchrony due to local, perhaps singular, micro-site features. Because of the small sample size, young age of the trees, and budgetary constraints, boxelder core information was not used in the final analysis except for calculation of a size-age relationship.

Vegetation Ecology

The fourth objective of this study was to inventory and evaluate the existing canyon bottom vegetation at WACA. Also, part of the second objective was to determine if dam construction in 1904 or 1940-41 has resulted in encroachment or elimination of true riparian vegetation which may have existed in the past and/or species/community changes. Initially, our objective was to perform a new sampling program. However, to take advantage of the January 1993 flooding, we decided to collect vegetation data from previously completed studies and examine existing lists of vascular plants.

Data Collection

Existing Data

Since several other vegetation surveys have been conducted in the canyon bottom of Walnut Canyon (Joyce 1974, 1976; Phillips 1990, and Jenkins et al. 1991), we decided to rely upon existing vegetation baseline data as our major source. Joyce (1974) set a series of eight, temporary 25 m line-intercept transects at regular intervals in the bottom of Walnut Canyon, four west of WACA's western boundary between it and Lower Lake Mary Dam, and four east of the eastern boundary.

During the spring and summer of 1988 and 1989, Jenkins et al. (1991) set up a single, permanent 15 m x 20 m plot, identified as WC2 (Figure 6), in the canyon bottom with the long axis parallel to the stream bed. This macroplot was subdivided somewhat strangely into 60, 2 m x 2 m subplots and 10, 2 m x 3 m subplots. Only perennial plant species counts or density and cover were estimated and recorded using a percentage scale of eight classes: <1, 1-5, 6-20, 21-40, 41-60, 51-80, 8 1-95, 95-100.

Phillips (1990) set up eight[10], permanent, approximately 375 m^2, rectangular macroplots of varying dimensions, usually 15 m by 25 m, in the bottom of Walnut Canyon (Figure 6). A modified riparian area survey and evaluation system (RASES) (U.S. Department of Agriculture, Forest Service 1989) was employed. Macroplots were subdivided into three subplot-strips parallel to the stream bed for the purpose of recording tree size-classes (<12.5 cm, 12.5-22.5 cm, >22.5 cm) and estimating cover and density. Understory vegetation was sampled using 50, 0.10 m^2 Daubenmire plots (Daubenmire 1968, Bonham 1989) arranged at one meter intervals along the boundary lines of the middle subplot-strip. Occasionally, Phillips added an additional sampling line if 50 plots could not be fitted along the subplot-strip boundary. Vegetation data recorded included species, cover, density, and frequency. Solar radiation data was also collected for each plot. Other data that Phillips collected, but did not recount in the final report, included estimates of surface composition: rocks, litter, and total natural cover with plant and litter cover combined.

In Phillip's final report (1990), data for all tree, shrub, and herb species were reported as relative cover, relative frequency, relative density, and importance value (IV). IV is the sum of the previous three values times 100. Refer to Mueller-Dombois and Ellenberg (1974) for a complete explanation of the IV concept. Separately, the absolute cover, frequency, and density were listed for the tree species only. In the final tally, data for the tree species collected in the three strips were incorporated into the data for the herbs and shrubs collected by the 50 plots. Coverage frequency of any herb and shrub species with canopy coverage in the plot was included for the 50 plots, while rooted frequency was taken for trees in the three strips. In order to obtain the IV, Phillips obtained the average relative cover for each herb and shrub species by dividing the sum of each species absolute cover by 50. Assuming that the average cover of a plot describes the cover over the entire transect area or the vegetation was homogeneous, this number was then divided by the sum of both the tree and herb/shrub cover times 100. The frequency data were obtained similarly. The relative density data for the herb/shrubs was obtained by multiplying the sum of the herb/shrubs data by 75 (375 m^2 divided by 50 plots), then this value was divided by the sum of the tree and herb/shrub times 100.

The RASES method calls for recording the canopy cover percentage of each species using seven classes (<1, 1-5, 5-25, 25-50, 50-75, 75-95, >95). However, estimates of actual cover percentage were recorded (B.G. Phillips, personal communication, 1994). Also, the RASES method does not call for the collection of frequency or density data for the 50 plots, nor for the computation of importance values for the species encountered.

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[10] The plots were surveyed in 1989 during the following dates: **Plot 1**-Sept. 15, **Plot 2**-May 26, **Plot 3**-May 23, **Plot 4**-June 16, **Plot 5**-June 9, **Plot 6**-June 14, **Plot 7**-June 20, **Plot 8**-Sept. 27.

Existing, aerial photography of WACA was examined to determine if changes in canyon bottom vegetation cover could be established over time. We reviewed the following photography: U.S. Forest Service (1949 and 1959, black and white photography at a scale of 1:15,000; 1984, black and white photography at a scale of 1:24,000; and 1990, color photography at a scale of 1:15,000) and National Park Service (1978, color photography at an approximate scale of 1:10,000). Generally, resolution of the photography was low and digitization would not have been fruitful. Individual or even community canopy could not be distinguished on the prints, and we did not pursue evaluation of change in canyon bottom vegetation cover thorough photographic comparisons. More importantly, no aerial photographs were found which predated the Upper Lake Mary dam.

Effects of the 1993 Lake Mary Overflow

In order to ascertain the effects of the fortuitous overflow from Lake Mary and subsequent flooding during January to April, 1993 on the canyon bottom vegetation, we relocated and resampled eight of Phillips' plots and the Jenkins et al.'s plot (WC2)[11]. Relocation of plots was facilitated by original site photographs and field data provided by the researchers. To the greatest extent possible, we repeated vegetation measurements for a simple comparison of the vegetational aspect before and after flooding. Also, we used the RASES method to collect data from Jenkins et al. (1991) WC2 plot.

Comparison Drainages Adjacent to Walnut Canyon

The fifth objective of this study was to inventory and evaluate nearby undammed drainages with similar canyon bottom vegetation communities to determine if they differ from Walnut Canyon. In order to identify these canyons which could serve as undisturbed "reference sites," maps were studied and knowledgeable people interviewed for their suggestions. The following canyons were identified: Anderson, Fry, Mormon, Padre, Youngs, Yellowjacket, Elliott, West Fork Oak Creek, Volunteer, and Sycamore. Field trips were undertaken to visit these drainages, prepare plant species lists, take documentary photographs, and ascertain the similarities and differences between the drainages and Walnut Canyon. A literature review of studies conducted in these drainages was undertaken to ascertain what information was already available for comparison.

Age and Size Distribution of Important Canyon Bottom Trees

Phillips' (1990) permanent vegetation monitoring plots in WACA were not randomly located. Instead, they were established in order to monitor and describe specific vegetation types . Also, size data for tree species located within her plots was coarsely subdivided into only three, broad size classes (see above). In order to more accurately determine the age and size distribution of canyon bottom tree species, ten, 12 x 20 m rectangular plots (0.24 ha total area) were randomly located within the stream channel of WACA. In order to fit the plots within the channel proper, the plots were oriented either with the long axis parallel or perpendicular to the channel. All

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[11] The plots were sampled during the following dates: **Plot 1**-Nov. 10, 1993; **Plot 2**-Oct. 22, 1993; **Plot 3**- May 31, 1994; **Plot 4**-Oct. 5, 1993; **Plot 5**-Oct. 14, 1993; **Plot 6**- June 10, 1994; **Plot 7**-May 26, 1994, **Plot 8**-June 21, 1994; and **Plot WC2**-Oct. 12 and 19, 1993.

plots were subdivided into 2 m wide strips in order to facilitate sampling. A random number between 50 and 150 was chosen as the number of paces (approximately 1 m) upstream from a point at the canyon bottom directly below the visitor center. The first of five plots was established at this location. Four successive random numbers were drawn to locate the rest of the plots by pacing the required distance from the previous plot. Five other plots were similarly located downstream. The length of the reach sampled was approximately one km.

Data were collected for each individual stem and included: species of tree; diameter at breast height[12] (dbh), to the nearest 0.1 cm; alive, dying or dead; whether the stem was resprouting, was itself the result of vegetative reproduction (i.e., a ramet) or a true seedling; whether the stem was erect, leaning or toppled and whether there was any evident flood damage. Incidental data collected included height of flood debris trapped by limbs and position of the stem relative to the main flow channel (within or peripheral). Cores taken for dendrochronological analysis were also used for age determination. Additional cores or cross-sections were taken from Gambel oak and Rocky Mountain Juniper. Additional cross-sections were taken from Arizona walnut and boxelder. Ten boxelder cores were taken from the West Fork of Oak Creek to compare growth rates with those from Walnut Canyon. Three cores were undatable due to damage. Size frequency histograms were constructed using 5 cm diameter classes except for the first or seedling class which was defined as all stems less than 1 cm in diameter. In the case of Gambel oak, some stems in this latter category were probably ramets manifesting from lignotubers or rhizomes.

Data Analysis

We organized both the existing data and newly collected data in spreadsheet files (Quattro Pro Version 5.0) and analyzed using the Cornell Ecology Package (Mohler 1987) programs TWINSPAN and DECORANA. TWINSPAN is a hierarchical, polythetic, divisive method of classification developed by Hill (1979a). DECORANA, or DEtrended CORrespondence ANAlysis, is an eigenvector-based ordination procedure related to reciprocal averaging developed by Hill (1979b). DECORANA is a computer based program designed primarily for plant ecologists who have collected data on the occurrence of a set of species in a set of samples. Classifications and ordinations of canyon bottom plots and species were derived from these applications. Flooding effects on vegetation were ascertained using simple side-by-side comparisons on a species-by-species and plot-by-plot basis. Analysis of age-size relationships was done using a combination of SPSS 6.0 and Quattro Pro.

RESULTS AND DISCUSSION

Recent History Relevant to Water Supply, Hydrology and Vegetation Change

Evidence of historical or pre-settlement conditions in Walnut Canyon can be gleaned from the history of the Flagstaff area. Two prehistoric, Sinagua Indian sites, located on San Francisco Wash several km downstream of WACA (Foreman 1941) were used by trappers, survey crews, pioneers, settlers, and their stock from the 1820's to 1880's (Smith 1991). The dwelling site and

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12 Breast height is defined as 1.5 m above the substrate.

associated small spring are both called Cosnino Caves and a water hole located about 0.5 km below is called Turkey Tanks. In 1853-54, Lt. A. W. Whipple passed by the drainage at Cosnino Caves exploring for a railway route. It is noteworthy that Whipple did not make note of flowing water in the drainage and only found permanent water at Cosnino Caves. During September 1857 and February 1858, Lt. E. F. Beale passed by Cosnino Caves exploring for a wagon road (Smith 1991). He noted that water was available at Cosnino Caves and upstream in Walnut Canyon, however he stated that the water level had dropped during the February return visit. Beale returned in April of 1859 and wrote, "Leaving last night's camp we traveled to Cosnino Caves and stopped to noon, at this place we found, as at Walnut Creek, a booming stream of water filling the whole bed of the creek..." (Smith 1991). In September 1870, John Marion, while accompanying General Stoneman's military post inspection, described the water hole as, "The tanks containing the water, are immense holes in the bed-rock of a large, dry stream..." These historic accounts support the fact that Walnut Canyon was an ephemeral stream channel, flowing seasonally with snow melt and summer rain.

In 1883, James Stevenson, visiting Walnut Canyon for the Smithsonian Institution, first reported on the cliff dwellings. In a letter written to John Wesley Powell[13] dated November 18, 1883, he described the cliff dwellings he had just visited and stated, "The hill which I examined contained about 60 houses, I could not learn of any water being near, but no doubt, in the ravines of the mountains not far distant an ample supply of water was found." Since he did not mention water flowing or being available in Walnut Canyon, and went out of his way to mention its probable availability elsewhere, we assume that no water was present during his November visit.
In 1884, during midsummer, Ms. R.T. Cross visited Walnut Canyon and stated, "Trails, of which there is now no trace, led down to the large, clear pools of water which abound in the canyon at this season of the year." Since Cross only mentions pools, we assume that water had ceased flowing and was only present in isolated, standing pools in the canyon floor.

Flagstaff was settled in the early 1880's and became the county seat of the newly formed Coconino County in 1891. The initial water sources for Flagstaff were Leroux Springs and Old Town Spring (Coconino Sun 1926), sources removed from Walnut Canyon. Though circumstantial, this early disregard of the nearby Walnut Canyon drainage suggests that Walnut Canyon was neither a permanent, nor reliable, water source.

An historic photograph (Figure 7A), dated 1886, was found in the Edgar A. Mearns collection from the Library of Congress (photo No. 121 labeled "Cosnino Cañon"). The photosite was located in the canyon bottom on the east side of the Third Fort Island. The present Visitor Center is sited above and to the left and just behind the high hill in the background. Though somewhat poor in quality, the photo shows a dry, open, somewhat rocky stream bed with a few herbaceous plants growing amongst the rocks. We assume that the photograph was taken in the late spring, summer, or early fall as trees in the canyon bottom are leafed out. Rephotography (Figure 7B) and visual survey of the photosite in July, 1994 shows that downcutting has been minimal. The two large boulders in the left foreground of the 1886 photo (Figure 7A) could not be identified

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[13] The original letter, written in pencil, is located in the National Anthropological Archives of the Smithsonian Institution. A five page copy was typed by the Bureau of American Ethnology staff at some time later. A photocopy of this transcription is on file in our office.

and appear to have been displaced. Even though boulders are still present (in the foreground), considerable silt has accumulated in the creek bottom which is far less rocky. More herbaceous vegetation is present, largely introduced weeds growing on the silty substrate. A large boxelder tree has become established in the background, behind the second rock outcropping on the right of the photo. Small trees have become established, such as the boxelder in the foreground. Interestingly, pinyon seem to have increased on the upland slopes.

The last half of the 19th century was a period of relative, but severe, drought in the Southwest which reached its nadir around the turn of the century before wetter conditions returned (Hastings and Turner, 1965). There is no telling what the hydrological conditions were prior to the drought, however, the 1886 photo (Figure 7A) is evidence that Walnut Canyon, within what is now the National Monument, was an ephemeral drainage almost two decades prior to the construction of Lower Lake Mary Dam in 1904.

A second photograph (Figure 8), dated 1897, was located in the National Anthropological Archives (NAA) of the Smithsonian Institution (Number NPC 028496.00, part of NAA photo lot 40, Arizona, Walnut Canyon) and is labeled "48. A. Walnut Cañon and Stream, Flagstaff, A.T. (Arizona Territory)." We have not been able to relocate the photo site, but the photograph does show a late winter - early spring scene, twigs of deciduous trees or shrubs with a few early leaves, and a still pool of water which mirrors the canyon walls. It is important to note that there is no flowing water and that this pool is a catch basin for snow melt.

Hydrology

Photographic and Anecdotal Evidence of High-Flows Through Walnut Canyon

Confirmation of high-flows traversing WACA and coinciding with spill events at Upper and Lower Lake Mary is difficult to obtain. Reports (Table 2) indicate that between 1904 and 1973 water has flowed through the canyon five times (Walnut Canyon National Monument 1976). Our knowledge of flow events through WACA comes from photographic, written, and anecdotal sources from the WACA files and personnel as well as the Flagstaff Water Treatment Plant. A photographic slide and print collection located in the WACA library documents flow in the canyon on April 16, 1939, May 1941, April 22, 1949, June 1968, April and May 1973, May 1983, August 12, 1987, and February 21, 1993.

Joyce (1974) documents high-flow through Walnut Canyon in early May of 1973. Joyce states that because of the high-flow, "observations [of vegetation] during most of May were limited to the rim." Therefore, it seems reasonable to assume that the canyon was already flooded by the early part of the month. According to city Water Treatment Plant records, Upper Lake Mary began overflowing on April 13, 1973 and stopped overflowing by the week of May 25, 1973. An unpublished survey of water pools along the streambed in WACA (Ellis 1973) states that Lake Mary overflowed in April 1973 due to 325 cm of snow that fell in the 1972-73 winter season augmented by 12.7 cm of moisture in March. In actuality, Upper Lake Mary overflowed on April 12 with Lower Lake Mary overflowing five days later on April 17 (Jack Rathjen, Water Treatment Plant Operator, Personal Communication). During this time, Flagstaff city engineers

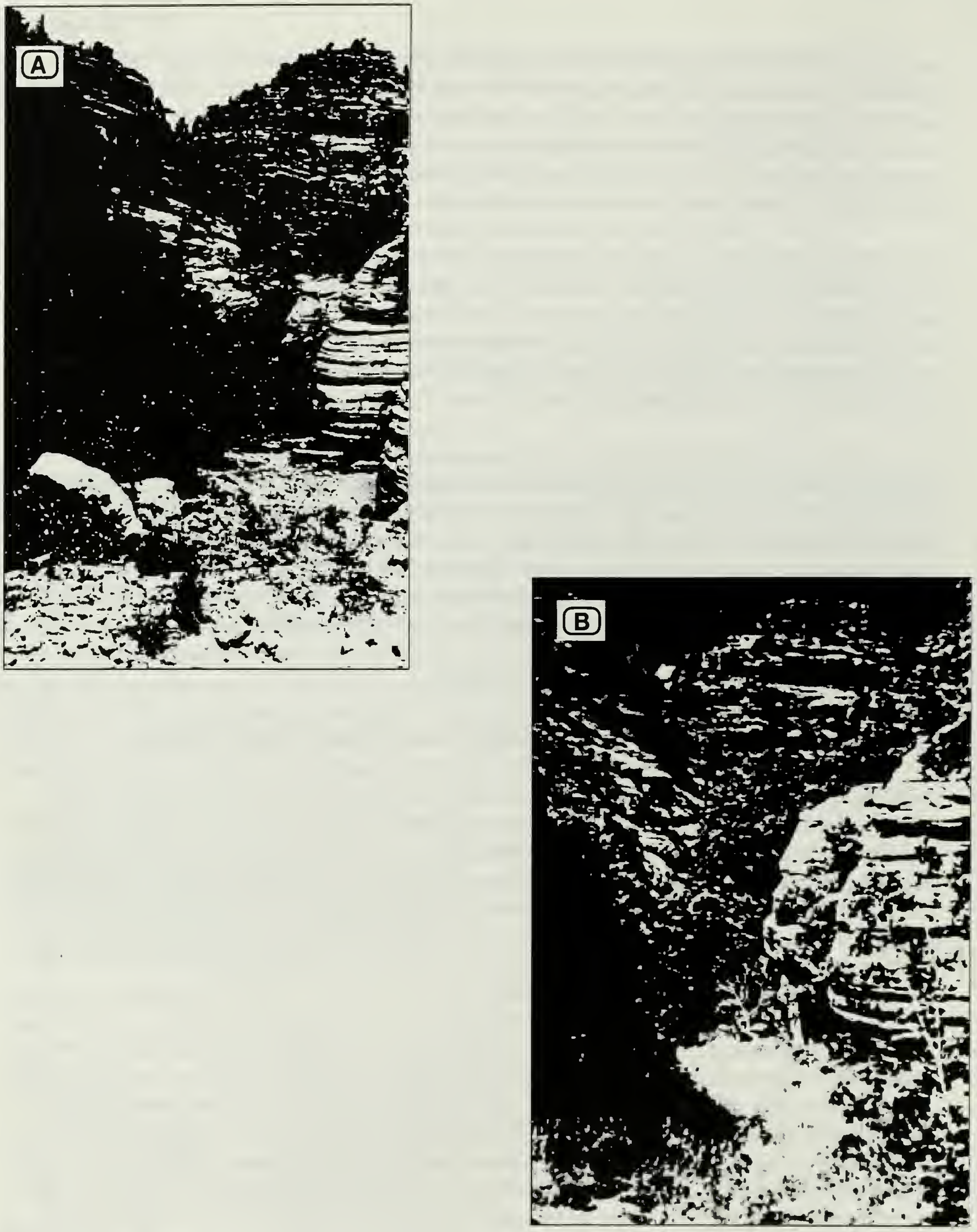

Figure 7. Historical photographic comparisons of the Walnut Canyon bottom east of the Third Island Fort. (A) Dry canyon bottom at Walnut Canyon, dated 1886 (from the Edgar A. Mearns collection, photograph number 121, labeled "Cosnino Cañon", from the Library of Congress. (B) Rephotograph from the same site taken July 1994 by Peter G. Rowlands.

Figure 8. Photograph of a pool at Walnut Canyon, dated 1897 from the Smithsonian Institution.

estimated an average flow of 750-850 cfs from Upper Lake Mary into Lower Lake Mary. No estimates were available of flow out of Lower Lake Mary into the Walnut Canyon Drainage. Flow was also estimated at WACA, by Vic Vieira, park ranger, on 14 May 1973, at 40 cfs. This flow receded quickly; one week later, flow was estimated at <10 cfs and no flow was evident five days later on May 28.

Summer and early fall flows sufficient to cause flooding of the Walnut Canyon drainage have been rare events and have only been documented in 1972, 1987, and 1991 (Table 2). An autumnal tropical storm in 1972 created runoff in Walnut Canyon. John Ray, a former Park Ranger at WACA, observed a major high-flow event in early October, 1972 in Walnut Canyon which lasted for several days and removed many large trees. High flows and slope runoff were delivered by tributaries to Walnut Canyon. After the waters subsided there were many standing pools in the canyon bottom which remained for a long time (John Ray, personal communication, 1994). The precipitation record for WACA revealed that 128 mm of precipitation fell between October 4 and October 7, 1972. The monthly total was 243 mm, a 771% change from the average of 28 mm. Unlike the localized thunderstorm described above, this was a widespread tropical disturbance which continued through most of the month. Phoenix's total October precipitation deviated 780% from the average, Prescott deviated 698%, and Flagstaff deviated 784% (Sellers and Hill 1974).

On August 12, 1987, WACA meteorological records show that a highly localized storm, centered almost directly over WACA, produced 103 mm of precipitation at the headquarters within a period of 60-70 minutes beginning at about 1:00 p.m.. On the same day, Flagstaff's weather station recorded only a trace of precipitation. The ensuing runoff was sufficient to cause Walnut Canyon to flow for a period of 24-48 hours. Photographs of this high-flow are archived in the WACA photographic library. "The canyon and its side drainages below the Monument visitors' center ran very hard" (Tom Ferrell, NPS Park Ranger, personal communication, 1994). WACA's superintendent, Sam Henderson (personal communication, 1994), drove down to Santa Fe Dam, located 10.5 km downstream from the visitor's center, to examine the effects of the flooding on that reach of the canyon and on the dam itself. He expected to find that water would be flowing over the dam, but instead, observed no water behind the dam. Ferrell made a rough estimate of the flow at around 200 cfs and remarked that the "water roared through the canyon" for a short amount of time. Within 48 hours, water below the visitor's center remained only in isolated pools.

Tom Ferrell (personal communication, 1993) recalled that in the summer of 1991, monsoonal runoff from a less violent and more widespread storm caused the drainage to flow for a couple of hours.

Statewide Floods of January 1993

Heavy and prolonged rains over Arizona, resulting from an unusual series of storms from the Pacific Ocean, from January 6-19, 1993, caused the most widespread and severe flooding since the turn of the century (U.S. Geological Survey 1993). The highest recorded flows were observed at streamflow gauging stations in every major river basin in the State by the

U.S. Geological Survey. Some stations reported multiple flood peaks. Precipitation ranged from 388% to 572% of normal, with greatest rainfall in the area north and east of Phoenix, though the entire State received precipitation in excess of 300% of normal. When compared to the flood of 1983, the statewide flood of 1993 was estimated to be 76% larger (U.S. Geological Survey 1993). National Weather Service records (National Oceanic and Atmospheric Administration 1993) show that precipitation at the Flagstaff Airport, for January and February was 239 mm and 251 mm respectively. At Walnut Canyon for the same months, precipitation was 137 mm and 164 mm respectively.

In 1993, Upper Lake Mary's storage capacity of 5.1 billion gal was exceeded between approximately January 14 and April 12. Rowlands and Brian observed flowing water on February 25 (Frontispiece). Water was not flowing through WACA prior to February 18 according to Tom Ferrell (personal communications, 1994). Jack Rathjen, Lake Mary Water Treatment Plant (personal communications, 1994) said that plant records showed that the initial overflow from Upper Lake Mary into Lower Lake Mary was around 176-180 cfs on January 17 and ended April 13 (87 days or 12.4 weeks later). Lower Lake Mary overflowed into the Walnut Canyon drainage from February 20 to April 16 (76 days or 10.9 weeks). In other words, there was approximately a five week (35 day) lag between the initial Upper Lake Mary overflow and high-flows in WACA.

Synopsis of Anecdotal, Written and Photographic Evidence For High-Flows

When Upper Lake Mary overflows, a high-flow event may occur in Walnut Canyon through WACA, provided that the duration and magnitude of the overflow are sufficient to (1) fill up Lower Lake Mary and cause it to overflow, and in turn (2) create a flow of sufficient magnitude to overcome water losses through fault fractures and bank storage (Figure 9). There is evidence that this could take up to a month in some cases. Obviously, one factor is the existing volume of water in Lower Lake Mary when Upper Lake Mary overflows. The duration of recorded Upper Lake Mary overflows have ranged from one week[14] to 13 weeks. There are a few recorded observations of spills from the reservoirs, but no measurements, which could be used to relate duration and magnitude of spills to flows in Walnut Canyon.

Six major overflow events (longer than five weeks duration) are recorded from Upper Lake Mary according to Flagstaff Water Treatment Plant records (Table 2). These overflow events occurred in 1973, 1979, 1980, 1983, 1985, and 1993. Walnut Canyon flows have been documented in 1973, 1983, and 1993 and probably, due to the long duration of Upper Lake Mary overflow, in 1979 and 1980. 1979. In 1979, the total duration of the spill was 10 weeks. On Apr. 6 the level of Lower Lake Mary was 23.4 ft reducing to 21 ft by May 4. During this event Lower Lake Mary Levels rose from 14.1 to 23.4 ft over 5 weeks, an influx from Upper Lake Mary of approximately 92 cfs. In 1980, the total duration of spill, according to the record, was 10 weeks, from March 7 to May 16. The only lake level reading prior to reaching the maximum depth was 20.6 ft on Mar 7. The Lake level remained at 20.7 from April 4 to May 2, 1980. The record was insufficient to estimate the flow from Upper Lake Mary. Although the Lower Lake Mary was

[14] The City of Flagstaff measures reservoir capacity weekly which limits the resolution of these time estimates somewhat.

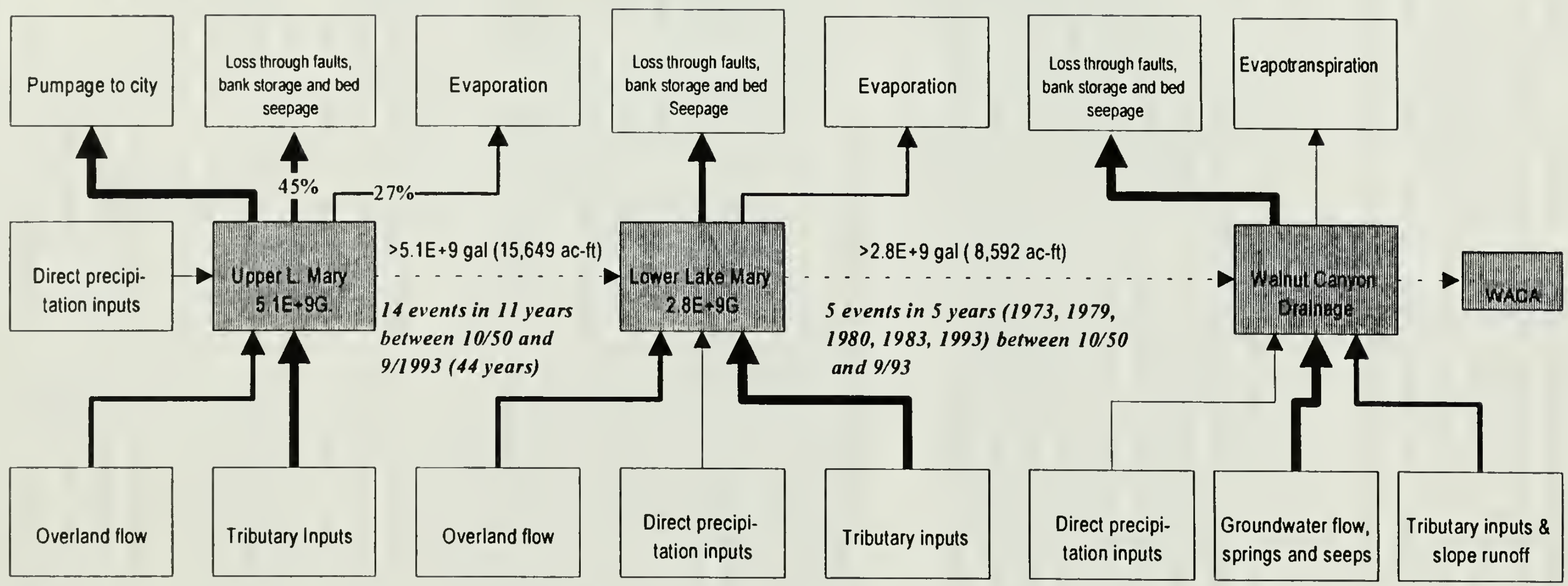

Figure 9. A simple model of the Lake Mary reservoir system. Lower Lake Mary was constructed around 1904 and became obsolete in 1941 when construction of Upper Lake Mary dam was completed and produced Upper Lake Mary as the principal impoundment. Domestic water pumpage for the city of Flagstaff is from Upper Lake Mary only. Lower Lake Mary is currently little more than a catch-basin. In order for flood flows to enter the Walnut Canyon drainage, water must first exceed the 5.1 billion gal (15,649 ac-ft) capacity of Upper Lake Mary and then the overflow must fill and exceed the 2.8 billion gal capacity (8,592 ac-ft) of Lower Lake Mary. Depending upon the rate of flow, the filling of Lower Lake Mary may take up to a month or more. Once Lower Lake Mary reaches capacity, additional inflow will cause it to spill over into the Walnut Canyon drainage. Because of major water loss through fault fractures, a flow of insufficient magnitude and/or duration will fail to reach Santa Fe Dam, below WACA's eastern boundary.

full in 1980, there are no actual written or recorded observations that a spill occurred. Four spills: 1973, 1979, 1983 and 1993 are validated by observations at Lower Lake Mary. Walnut Canyon National Monument photographic or written records corroborate 1973, 1983 and 1993 spills, but we could find no corroboration of the 1980 event either from City of Flagstaff or NPS sources. A back-issue search of the local newspaper, *The Arizona Daily Sun*, of March and April, 1980 revealed no articles reporting an overflow into the Walnut Canyon Drainage. This would not be unusual since even the major high-flow of 1993 was relegated to the back pages of the newspaper and a less important overflow might not be reported at all if no damage was being done to county roads or private property as was the case in 1993. Nevertheless, we assume that Lower Lake Mary dam overflowed because of the long duration of spillage from upper Lake Mary together with two consecutive monthly Lower Lake Mary depth measurements (April 4, 1980 and May 2, 1980) showing a maximum depth of 20.7 ft.

Tom Ferrell (personal communication 1993) stated that Walnut Canyon did not flow in 1985 even though Upper Lake Mary was overflowing. Apparently, Lower Lake Mary filled, but never overtopped. No major non-summer events are recorded prior to 1973 nor was any photographic, written, or anecdotal evidence discovered. This is not surprising since the 1950's and 1960's were relatively droughty periods throughout the Southwest (Neilson, 1986). Summer high-flows of more than two days duration within WACA have been documented in October 1972, the result of a tropical storm, and in August 1987, the result of an intense, localized thunderstorm. It should be noted that *at no time were any of the above events gaged within WACA, other than by gross visual estimate.* No quantitative estimates of discharge are available.

Effects of Upper and Lower Lake Mary

Three overflow scenarios were developed which estimate the effects of Upper and Lower Lake Mary Dams on spills and subsequent high-flows through Walnut Canyon. The three scenarios are: no dams; Upper Lake Mary dam only, and both Upper and Lower Lake Mary Dams in place.

No Dams

Since 1950, when records are available, it was assumed that any inflows into the drainage at Upper and Lower Lake Mary flowed directly into Walnut Canyon in the absence of the dams. Calculation of these estimates is described in the Methods section. Table 3 and Figure 10 summarizes the results.

Data indicate that between October 7, 1950 and September 30, 1993 measurable inflow into Upper Lake Mary was recorded in 377 out of 2,242 weeks (i.e., records) , about 17% of the time. The flow-frequency distribution histogram declines continuously with increasing flow (Figure 10). Flows between 0 and ≤50 cfs occur 64% of the time when inflows occur. Flows above 200 cfs occur only about 5% of the time, or < 1% of the time since 1950.

The data also suggest that although large inflows are rare they may be the primary indicator that Lower Lake Mary filled and flow occurred in Walnut Canyon. It appears that a very small number of temporally restricted, high runoff events (>200 cfs), contributed the greatest flow into

Table 2. A summary of documented spills from Lower Lake Mary into Walnut Canyon since 1939. Note that in 1985, Lower Lake Mary reached a maximum depth, but did not overflow.

Date	**Source of Flow**	**Photographic Evidence**	**Observations**
April 16, 1939[1]	Probably Dam Spill	YES	None known
May, 1941	Probably Dam Spill	YES	None known
April 22, 1949	Probably Dam Spill[2]	YES	None known
June, 1968	Probably Thunder Storm[3]	YES	None known
October 4-7, 1972	Autumn Tropical Storm	YES	Anecdotal
May 4-25, 1973	Dam Spill	YES	Anecdotal/Quantitative
Apr 6-May 16, 1979	Dam Spill	NO	Quantitative
Mar 7-May 16, 1980	Dam Spill	NO	Quantitative
Apr 1-June 3, 1983	Dam Spill	YES	Quantitative
Aug 12, 1987	Summer Thunderstorm	YES	Anecdotal
Summer, 1991[4]	Summer Thunderstorm	NO	Anecdotal
Feb 25-Apr 27, 1993	Dam Spill	YES	Anecdotal/Quantitative

1 Upper Lake Mary Dam had not yet been built so this spill was probably the result of far less runoff than occurred in the subsequent spill years indicated below.

2 Records not kept prior to 1950.

3 The Upper Lake Mary Database shows that the Lake Level of Upper Lake Mary was below the spillway (38.5 ft maximum Lake Depth) throughout the entire month of June ranging between 34.8 and 35.9 feet.

4 No specific date given, recollection of Park Ranger, Tom Ferrell

Table 3. Scenarios estimating the effects of Upper and Lower Lake Mary Dams on reservoir spills and subseqent flood flows through Walnut Canyon. Flows are presented for each scenario for discrete flow classes.

	No Dams in Place			**Only Upper Lake Mary Dam in Place**[1]			**Both Dams in Place**
Inflow (cfs) to Upper Lake Mary According to Discrete Flow Classes	Estimated Reduction in Flood Duration	Estimated No. of Weeks of Inflow[2]	Estimated No. of Years out of 44 Having Flow Levels Within Classes	Estimated Reduction in Flood Duration	Estimated No. of Weeks Showing Inflow	Estimated No. of Years out of 44 Having Flow Levels Within Classes	Due to the scarcity of quantitative data on Lower Lake Mary reservoir levels (stage), for most of the record, monthly readings only)and the absence of discharge data below Lower Lake Mary, no estimates of inflow could be computed for flow classes.
0-50	None	242 (10.8%)	41	81%	39(1.5%)	11	
50-100	None	71 (3.2%)	32	99%	1 (0.04%)	1	
100-150	None	25 (1.1%)	19	100%	0 (0%)	0	
150-200	None	20 (.9%)	14	100%	0 (0%)	0	
>200	None	19 (0.8%)	15	90%	2 (0.09%)	1	
Estimated Total Ac-Ft Into Walnut Canyon in 44 Years	**289,410**[3]			**25,163**[4]			No estimates could be calculated given the available data
Number of Years with *Any* Flow[5]	**43 out of 44** (93%)			**11 out of 44** (25%)			**5 out of 44**[6] (11%)

1 This scenario assumes that, in the absence of Lower Lake Mary Dam, all overflows from Upper Lake Mary are delivered directly into the drainage and eventually flow into Walnut Canyon. In constructing this scenario it was assumed that inflow after at maximum depth resulted in equivalent overflows into Walnut Canyon (see methods section and Appendix III).

2 The number of weeks of flow is based on a record of weekly events beginning October 7, 1950 to September 30, 1993 or a total of 2,242 weeks.

Table 3. Continued

3 This estimate was derived by assuming that any positive inflows into Upper Lake Mary (as defined in the methods section) were delivered into the draingage instead of being impounded behind Upper Lake Mary Dam. The resulting figure is the cummulative sum of such positive flows over 44 years This is probably a conservative estimate since neither bank storage nor evapotranspiration is accounted for.

4 This estimate was derived in a similar fashion as above except that Upper Lake Mary is present and the figure is the 44 year cummulative sum of the flows described in footnote 1 above.

5 Note: this is not the total of column three under each scenario above; inflow in several flow classes could occur in one year.

6 Determined from anecdotal and photographic records (refer to Table 2).

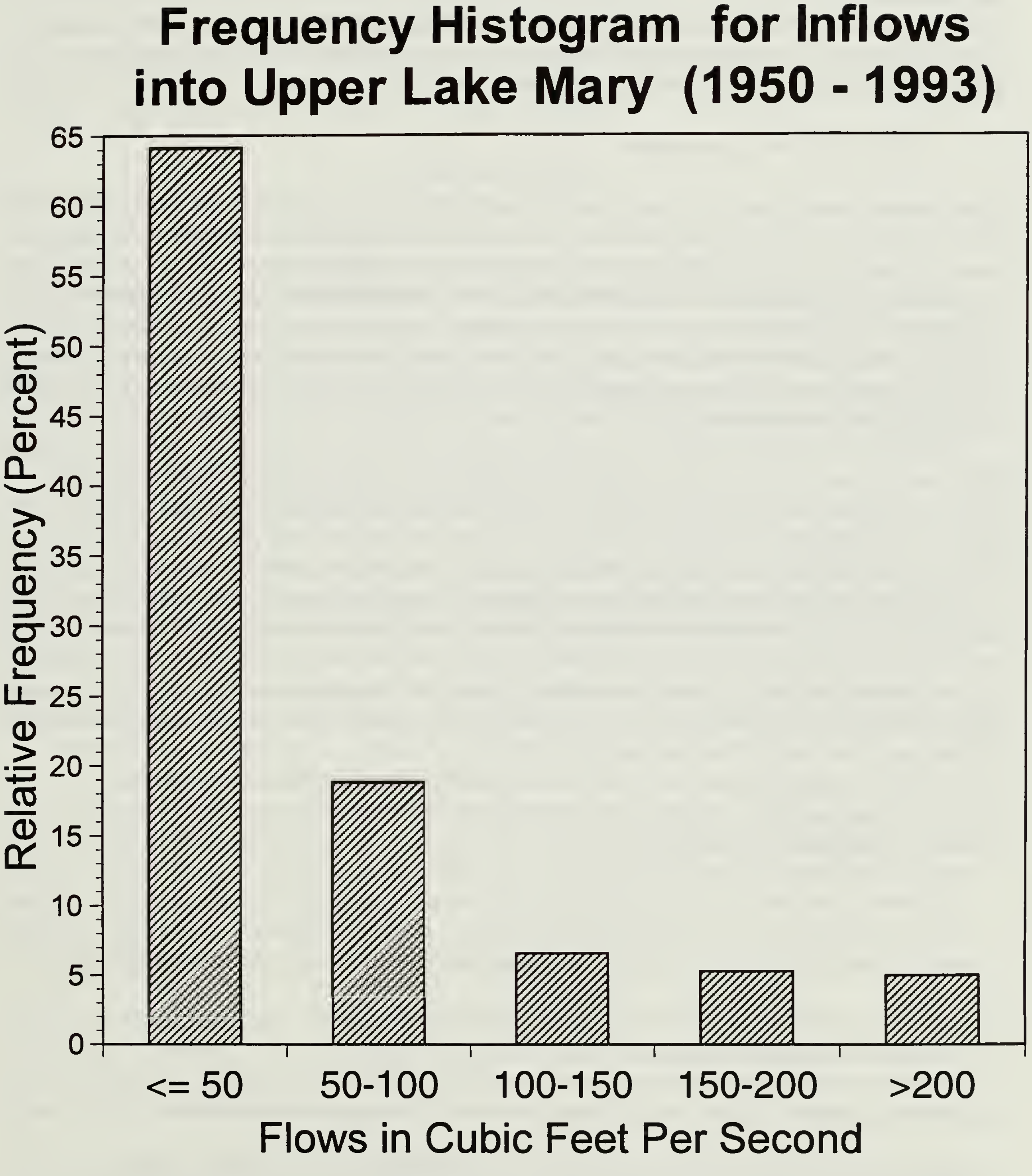

Figure 10. Distribution of inflows into Upper Lake Mary (ULM) over 44 years (1950-1993).

Upper Lake Mary; about 94,188 ac-ft since 1950. Total inflow over the entire period, was estimated to be 289,410 ac-ft. The actual amount may be somewhat larger since evaporation was not considered. It is difficult to say whether or not smaller flows (≤50 cfs) would have occurred in WACA without the presence of the dams. The hydrological setting i.e., fault fractures and sink holes, as well as bank storage between the reservoirs, and the WACA boundary, could reduce or eliminate flows into Walnut Canyon.

Upper Lake Mary Dam Only

This scenario never occurred in reality since Upper Lake Mary Dam post-dates Lower Lake Mary Dam. However, we felt that this scenario was needed in order to demonstrate the potential impacts that the presence of one dam could have on flows through Walnut Canyon. A two dam scenario would yield impacts at least this great. As mentioned earlier, a scenario evaluation the impacts of Lower Lake Mary only was not attempted due to the lack of consistent lake level and flow data. Because of the smaller capacity of Lower Lake Mary, the effect of this dam alone on flow frequency and duration is assumed to be somewhere between the effects of no dams in place and Upper Lake Mary Dam only.

This scenario was constructed by sorting the database for records with both a maximum lake depth and inflow onto Upper Lake Mary. Such an occurrence was interpreted as an Upper Lake Mary spill. Without Lower Lake Mary Dam in place, the overflow was assumed to travel down Walnut Canyon. The results are shown in Table 3. In comparison with the "no dams" scenario, reductions in the estimated flow frequency across all discharge classes are indicated. Total estimated runoff delivered into the Walnut Canyon drainage over the 44 year period is reduced by a factor of ten from 289,410 to 25,163 ac-ft. High-flow records (>200 cfs) are reduced from 19 to 2. Smallest flows (≤50 cfs) are reduced from 242 to 66 and annual flow frequency is reduced from 93% to 25 % of the time. Discharge in the 50-150 cfs classes is similarly reduced. According to the model, there are no flows into Walnut Canyon in the discrete 100-150 and 150-200 cfs discharge classes due to inflow and reservoir level conditions modeled.
It is likely that these flow classes occur, but were not modeled in this instance due to the use of weekly (as opposed to daily) data.

Both Dams

It was not possible to construct this scenario from available hydrologic data for the following reasons:

(1) Lake level measurements of Lower Lake Mary are limited.

(2) No measurements of flow below Lower Lake Mary Dam have ever been made.

(3) Due to a lack of quantitative data, no clear understanding about the inflow-outflow relationship between Upper and Lower Lake Mary exists[15]. Observations and anecdotal

[15] In the absence of flow gages it is difficult to determine the actual flow rate from Upper Lake Mary, once its stage reaches or exceeds 38.5 feet, into Lower Lake Mary. A short-duration

information of Lower Lake Mary spills are the only information available to indicate when flows entered Walnut Canyon.

In summary, since 1950, Walnut Canyon probably would have flowed 43 out of 44 years without dams in place. If one were to consider a one dam scenario, flows would have occurred in 11 out of 44 years. With both Upper and Lower Lake Mary Dams in place, Walnut Canyon has flowed in WACA five times since 1950, about once every 8.8 years.

Dendrochronology

Site Specific Chronologies from Walnut Canyon

Only increment cores from ponderosa pine and Arizona walnut yielded adequate tree-ring chronologies. Cores from boxelder and narrowleaf cottonwood were extracted, but due to the short-lived nature of these tree species, none of the cores examined represented pre-Lower Lake Mary Dam (i.e., 1904) conditions. In addition, many of the cores were broken or damaged and could not be adequately analyzed. Results for these species will not be presented here. A statistical summary of the short-term WACA site-specific chronologies is presented in Table 4.

Ponderosa Pine, Rim/Slope Chronology

Cores collected from ponderosa pine trees occupying canyon rim/slope sites yielded the chronology presented in Figure 11. The cross-correlations of this ring index chronology with other such series along with probability (i.e., significance levels) are presented in Table 4. This chronology cross-correlates significantly at zero lag with the ponderosa pine canyon bottom chronology (see below) as well as with the Arizona walnut and WACA, long-term ponderosa pine chronologies. The cross-correlation of the rim/slope chronology with the WACA long-term

Ponderosa Pine, Canyon Bottom Chronology

This chronology was prepared from trees growing in and directly adjacent to the Walnut Canyon bottom where a former riparian zone probably would have been. Overall, year-to-year variation and inter-tree correlation of ponderosa pine ring widths from the riparian zone were lower than those from rim sites and slopes of WACA. Since the canyon bottom is a more complacent site, this is to be expected.

The usable chronology, like that of the rim/slope trees was about 200 years in length. All cross-correlations (Table 4) are at zero lag and are significant. Interestingly, this ring width index chronology cross-correlates with the Flagstaff Airport mean annual precipitation at a somewhat higher significance level than the rim/slope indices ($r = 0.539$ vs. $r = 0.365$) indicating that the

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high inflow from Upper Lake Mary may serve only to fill Lower Lake Mary while a long-term, low velocity flow may eventually fill up the lake and consequently create a spill. Also, lake level of Lower Lake Mary prior to Upper Lake Mary spill events is a critical factor. Observations at the dams indicate that tributary overland flow is capable of raising Lower Lake Mary lake levels to as much as 11 feet, even before Upper Lake Mary spills over.

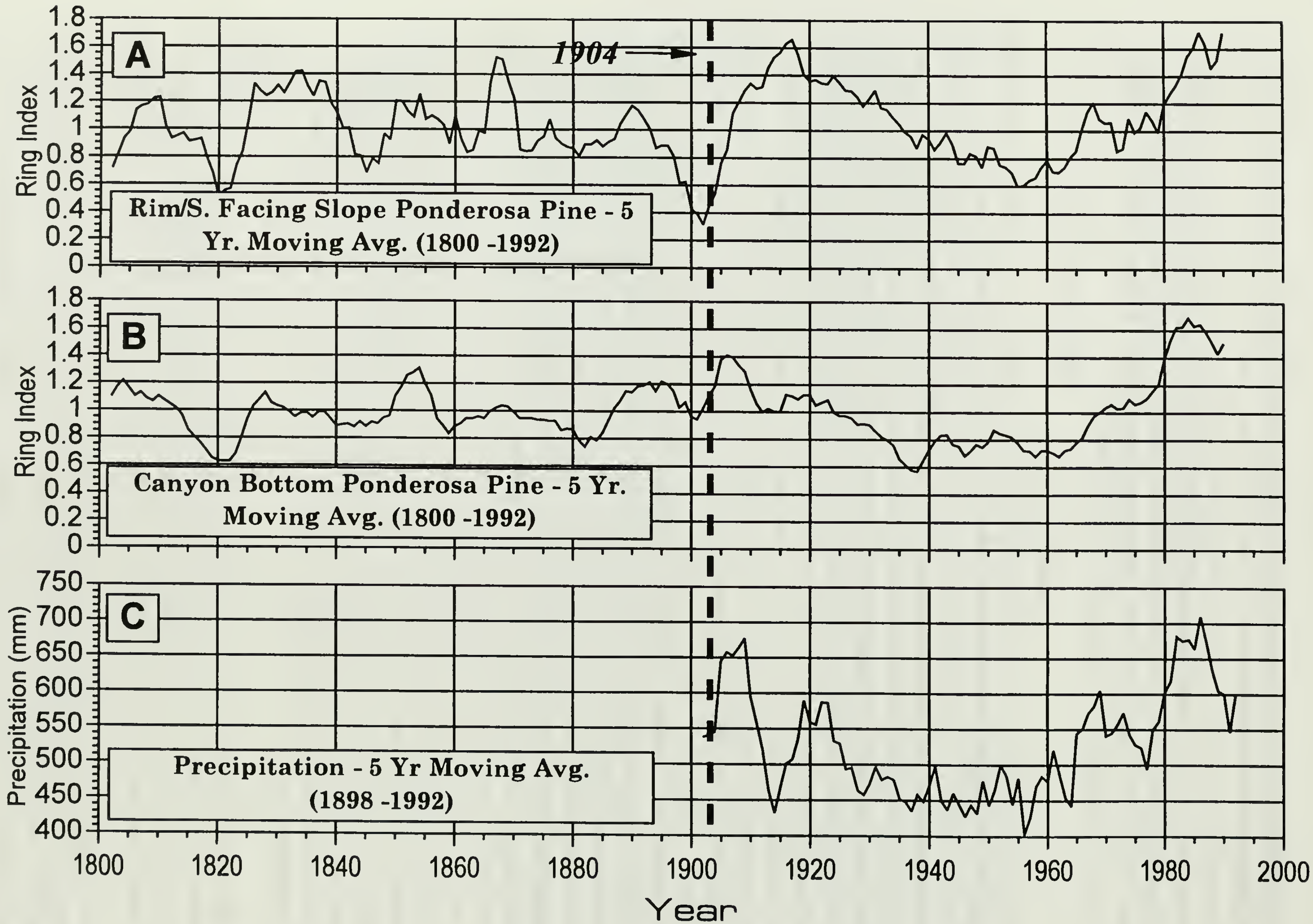


Figure 11. Ring indices (1800-1992) from ponderosa pine cores collected from the rim/south-facing slopes and canyon bottom (dewatered riparian zone) of Walnut Canyon National Monument. The indices are plotted as 5 year moving averages. The Flagstaff precipitation record (1898-1992) is included for comparison.

canyon bottom chronology "tracks" the Flagstaff precipitation record better. Conversely, the rim/slope chronology correlates much better with the WACA chronology at a much higher level of correlation than does the canyon bottom chronology ($r = 0.902$ vs. $r = 0.387$). Both ring index records cross-correlate highly significantly with the Flagstaff precipitation record since 1898 (Table 4). The ring index record of the canyon bottom trees, growing in the more complacent site, cross-correlates with Flagstaff precipitation better than the rim/slope trees. This observation should not be interpreted as contrary to the concept of the canyon bottom as a complacent site, i.e., one whose tree-ring growth is less sensitive to climatic fluctuations (Stokes and Smiley 1968). The better correspondence with the precipitation record may be due to the fact that the Walnut Canyon drainage acts to channel precipitation from side canyons and therefore integrates precipitation on a drainage wide basis, below Lower Lake Mary Dam. On the other hand, trees on the WACA rim and slopes will respond only to precipitation events on site. This consideration becomes particularly important during the monsoon season. Summer thunderstorms are often highly localized and erratic.

We have shown previously that in August of 1987, a 4.01 inch downpour at WACA was accompanied by a mere trace recording at Flagstaff. It is unfortunate that the 1951 to present precipitation record at WACA is not long enough to form the basis for an adequate analysis. However, by cross-correlating the WACA, site-specific precipitation record from 1951 to 1992 with rim/slope and canyon bottom ponderosa pine annual ring indices we obtain highly significant coefficients of 0.474 ($t = 3.405$, $df = 40$, $p = 0.00152$) and 0.422 ($t = 2.944$, $df = 40$, $p = 0.00537$) respectively at lag zero. The cross-correlation with Arizona walnut annual ring indices, though significant, is only 0.313 at lag zero ($t = 2.084$, $df = 40$, $p = 0.0436$) but 0.409 at lag 1($t = 2.799$, $df = 39$, $p = 0.00396$). In other words, the rim/slope is indeed the more sensitive site, though only slightly more so, relative to the canyon bottom, as revealed by cross-correlation with the site-specific precipitation record.

Arizona Walnut Chronology

Tree-ring chronologies for Arizona walnut and for ponderosa pine were highly synchronous and correlated (Tables 4 and 5). Although there were no locally absent rings and only a few micro rings in 1956 and in 1971, year-to-year variation and inter-tree correlation of ring widths were high. Tree ages varied from 44 to 143 years with a final chronology starting in 1859 and continuing through 1992. All other cross-correlations, including that with mean annual precipitation for Flagstaff, were significant (Table 4).

Growth Patterns of Ponderosa Pine and Arizona Walnut in Relation to Periods of Dam Construction

The mean tree-ring index of ponderosa pine cores collected from the rim/south facing slopes, and canyon bottom of WACA were calculated over three critical time periods: prior to 1904, before any dams were in place; 1905 to 1941, after the construction of Lower Lake Mary Dam and before the construction of Upper Lake Mary Dam; and 1942 to 1992, after both dams were

Table 4. Summary of cross-correlation analyses for Walnut Canyon tree-ring chronologies and the Flagstaff precipitation record for the period 1898 through 1992.

Cross Correlation Comparison:	Mean Annual Precipitation	Ponderosa Pine, Rim/Slope Chronology	Ponderosa Pine, Riparian Chronology	Arizona Walnut Chronology	Walnut Canyon Ponderosa Pine (WACA) Chronology
Time Period:	1898 - 1992	1800 - 1992	1800 - 1992	1855 - 1992	1414 - 1987
Mean Annual Precipitation	NA	**r = 0.365** (0, 95)[1] t = 3.781[2] p = 0.000138	**r = 0.539** (0, 95) t= 6.170 p = 8.75E-9	**r = 0.338** (0, 95) t= 3.463 p = 0.000404	**r = 0.227** (3, 90) t = 2.187 p = 0.0157
Ponderosa Pine, Rim/Slope Chronology		NA	**r = 0.528** (0, 193) t = 8.592 p = 1.55E-15	**r = 0.488** (0, 133) t = 6.399 p = 1.28E-09	**r = 0.902** (0, 188) t = 28.493 p < E-15
Ponderosa Pine, Riparian Chronology			NA	**r = 0. 426** (0, 133) t = 5.389 p = 1.59E-7	**r = 0.387** (0, 188) t = 5.724 p = 2.05E-8
Arizona Walnut Chronology				NA	**r = 0.322** (0, 133) t = 3.818 p = 0.000103
Walnut Cyn. Ponderosa Pine (WACA) Chronology					NA

[1] The numbers in parentheses represent, respectively , the lag followed by the number of overlapped positions.

[2] The t-statistic is calculated as $t = \text{sqrt}((n^*-2)/(1-r_m^2))$ where n^* is the number of overlapped positions between the two sequences and r_m is the cross correlation coeficient at the matched position (Davis 1986).

Table 5. Statistics of tree-ring chronologies.

Species (Site)	First Year	Last Year	Record Length	Mean Sensitivity	Standard Deviation	First-Order Autocorrelation
Ponderosa pine (Rim/slope sites)	1800	1992	193	0.44	0.43	0.361
Ponderosa pine (Canyon bottom)	1800	1992	193	0.17	0.27	0.667
Arizona walnut (Canyon bottom)	1855	1992	138	0.34	0.38	0.497

established (Figure 11A). Variation in rim/slope ring index means was employed as a reference to compare similar values for canyon bottom ponderosa pines. The latter, if affected by dewatering caused by the Lake Mary Dams, should exhibit a decline in growth (i.e., ring index values) subsequent to dam construction.

The mean tree-ring index of ponderosa pine trees on the canyon rim and upper slopes has changed, when calculated over the three defined time periods, changing from 0.972 ± 0.041 to 1.247 ± 0.049 to 1.041 ± 0.071 (Figure 11A). In comparison, mean tree-ring indices of ponderosa pine trees in the bottom of WACA do not appear to have changed over time in response to construction of the Lake Mary Dams and subsequent dewatering of the drainage (Figure 11b). The mean ring index varied from 0.986 ± 0.020 when calculated over 1800-1904 to 0.983 ± 0.044 between 1905 and 1941 and then rose slightly to 1.042 ± 0.053 between 1942 to 1992. The variance did not remain more-or-less constant over these time periods and for rim/slope indices changed from 0.175 to 0.088 to 0.253. Variances for canyon bottom trees were lower and changed less drastically from 0.041 to 0.071 to 0.141, but followed the same pattern: first decreasing, then increasing. Over the length of the ring index record, the mean ring index for rim/slope trees was 1.044 ± 0.031, and for canyon bottom trees, 1.000 ± 0.019. Though the means were similar, the respective variances (0.188 and 0.073) were significantly different ($F = 2.588$, $p = 0.000848$) even after adjustment of the number of observations downward (Dawdy and Matalas 1964) for autocorrelation effects (193 to 37 in response to a first order autocorrelation of 0.677 and 193 to 91 in response to a first order autocorrelation of 0.361 respectively). The higher variance of the ring index for the rim/slope trees is consistent with an interpretation of this site as more sensitive than the canyon bottom.

The period after 1942, especially during the 1950's was one of drought in the Southwest (Neilsen 1986) and is revealed in the Flagstaff annual precipitation series in Figure 11. Growth rates of the more sensitive rim/slope trees declines in response. In contrast, the more slowly growing canyon bottom ponderosa pines situated in a complacent site were less responsive to changes in climate. The mean deviations of canyon bottom annual tree-ring indexes from contemporaneous rim/slope ring indexes calculated over the critical time periods (Figure 12C) are due primarily to the changes in the index calculated for rim/slope trees. These values changed from -.0135 ± 0.038, with the canyon bottom trees growing slightly faster; prior to 1904 to .2637 ± 0.053, with the rim and slope trees growing about 1.3 times as fast; and to 0.004 ± 0.043, with the rim and slope trees growing slightly faster.

Changes in the Arizona walnut mean ring index over time were similar, although more pronounced, to canyon bottom ponderosa pine (Figure 12D). The mean ring index appears to have decreased substantively from 1.035 ± 0.056 between 1855 and 1904 to 0.870 ± 0.048 between 1905 and 1941 and then increased to pre-1904 levels, 1.060 ± 0.056 between 1942 and 1992. The depression of the ring index mean during the time between dams is unexplained.

In summary, there is no compelling evidence that the construction of the two dams in the Walnut Canyon drainage has had any effect on the growth rates of either Arizona walnut or ponderosa pine trees growing in the bottom of Walnut Canyon as reflected in changes in the mean tree-ring index.

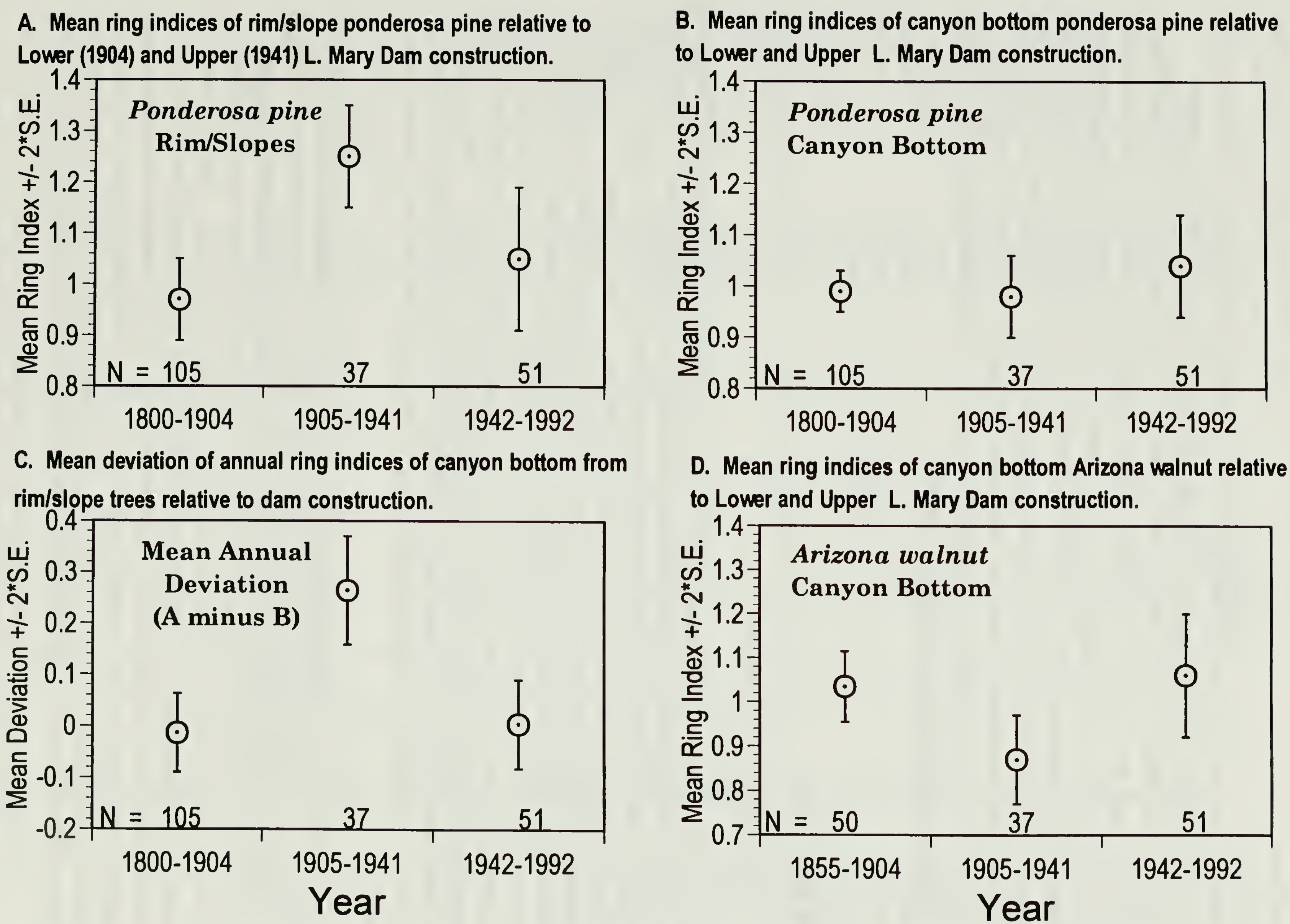


Figure 12. Changes in the mean tree-index for ponderosa pine (rim/slope and canyon bottom sites) and Arizona walnut (canyon bottom) over discrete time periods associated with the construction of Upper and Lower Lake Mary DamS.

Flood Scars

None of the tree cores collected by this study showed evidence of flood scars. However, after the cores were collected, it became apparent that they had not been collected from the proper position for scar dating. When a tree is tilted by a force, such as a high-flow, but also gravity, wind, avalanches, etc., a type of scar called reaction wood is formed (Westing 1968, Hughes 1965). After tilting, the side facing the force is "tensed" and the opposite side is "compressed" (Sigafoos 1964, Malanson, 1993). In coniferous species, such as ponderosa pine, reaction wood occurs on the compressed side and is termed compression wood. In angiosperm species, such as boxelder and Arizona walnut, it occurs on the tensed side and is termed tension wood. Thus, cores used to date scars or reaction wood must be taken from the downstream side for coniferous species and the upstream side for hardwood species.

Vegetation

1989 Study Plots

TWINSPAN Classifications

Plots. Results from the application of TWINSPAN to the vegetation data collected in 1989 along the Walnut Canyon bottom (Phillips 1990) are presented in Table 6 and Figure 13. TWINSPAN classifies vegetation into assemblages, based upon the presence of differential species, i.e., species present only in certain groups or stands of vegetation and not in others. The primary division separates the first seven plots (Clusters A and B) from Plot 8 (Cluster C), termed by Phillips (1990) as representing an "annual disclimax." Indeed, six plant species, all of them annuals or short-lived perennial herbs typify Plot 8. Downy chess, dragonsage, Russian thistle, and motherwort are the dominant species. This assemblage is prominent on the sediments which have accumulated behind Santa Fe Dam, extending upstream for over 2.5 km. Similar annual disclimax assemblages are common throughout the bottom of Walnut Canyon, often occurring in areas of the normally dry stream bed where fine sediments have filled formerly scoured, deep pools.

The remainder of the plots appear to be examples of transitional or successional plant assemblages invading the normally dry canyon bottom. Plots 2, 4, 1, and 6 (Cluster A, Figure 13) are similar in that red osier dogwood[16], the differential species separating this group from Plots 3, 5, and 7 (Cluster B, Figure 13), is present in each plot. Clematis is common to these plots but also occurs in Plot 3. Boxelder occurs in every plot except Plot 8. Clematis and boxelder are not particularly good differential species, nor are Arizona rose, downy chess, or Arizona grape. Plot 2 occurs just downstream from Ranger Canyon and includes a talus slope along the northern half of the plot which extends into and includes the old stream bed and thence up the opposite bank to the south canyon wall. New Mexico locust, Arizona rose, and red osier dogwood are prominent in the dry stream bottom. The talus slope is almost excusively occupied

[16] Red osier dogwood (*Cornus stolonifera*), according to Welsh et al. (1987) occurs in the eastern United States and the species in the West is considered by them to be *C. sericea*.

Table 6. TWINSPAN nodal analysis of 1989 (Phillips 1990) canyon bottom vegetation data. Horizontal lines drawn at division level 3.

Species	Alpha Code	Stand Order								Species Division Level
		2	4	1	6	7	3	5	8	
Arizona walnut	JUMA			3	2	1				00000
Aspen	POTR				1					000010
Narrowleaf hoptree	PTAN			1						000010
False solomon seal	SMRA				1					000010
Squaw bush	RHTR			1	1					000010
Service berry	AMUT				1					000010
Bonpland willow	SABO			1						000010
Snowberry	SYPA		1	1	3					000010
Red osier dogwood	COST	1	1	2	4					000011
Bee balm	MOME		1	1	1					000100
Poison ivy	TORA		1	1						000100
Douglas fir	PSME		2		1					000101
Ponderosa pine	PIPO		1							000101
Goldenrod	SOSP	1	1		1					000101
Rocky Mountain juniper	JUSC		5	1		1				00100
Gambel oak	QUGA		2	1				1		00100
Arizona grape	VIAZ	1	1	1			1			00101
New Mexico locust	RONE	2	1							0011
Desert olive	FOPU	3								0011
Clematis	CLLI	1	1	1	1	1	1			01000
Arizona rose	ROAR	2		1	1		2	1		01001
Thicket creeper	PAVI	3		1		1	1	1		01001
Meadow rue	THFE			1	1		1	1		01010
Mutton grass	POFE			1			1			01010
Dogbane	APCA		1					1		01011
Little bluestem	SCSC		1					1		01011
Boxelder	ACNE	1	1	3	1	8	4	1		0110
Wormwood	ARLU				1	1		1		0110
Narrowleaf cottonwood	POAN			1		5	8			0111
Magellans phacelia	PHMA			1		1	1			0111
Downy chess	BRTE	1	1	1		1	1		1	10
Hop	HUAM				1	1			1	10
Dragon sage	ARDR				1	1	1	1	4	110
Russian thistle	SAIB								4	1110
Motherwort	LECA								2	1110
Sedge	CAOC								1	1110
Milk vetch	ASTE								1	1110
Wheatgrass	AGSM								1	1110
Canada wild rye	ELCA								1	1111
Stand Division Level:		0	0	0	0	0	0	0	1	
		0	0	0	0	1	1	1		
		0	1	1	1	0	1	1		
				1	1					

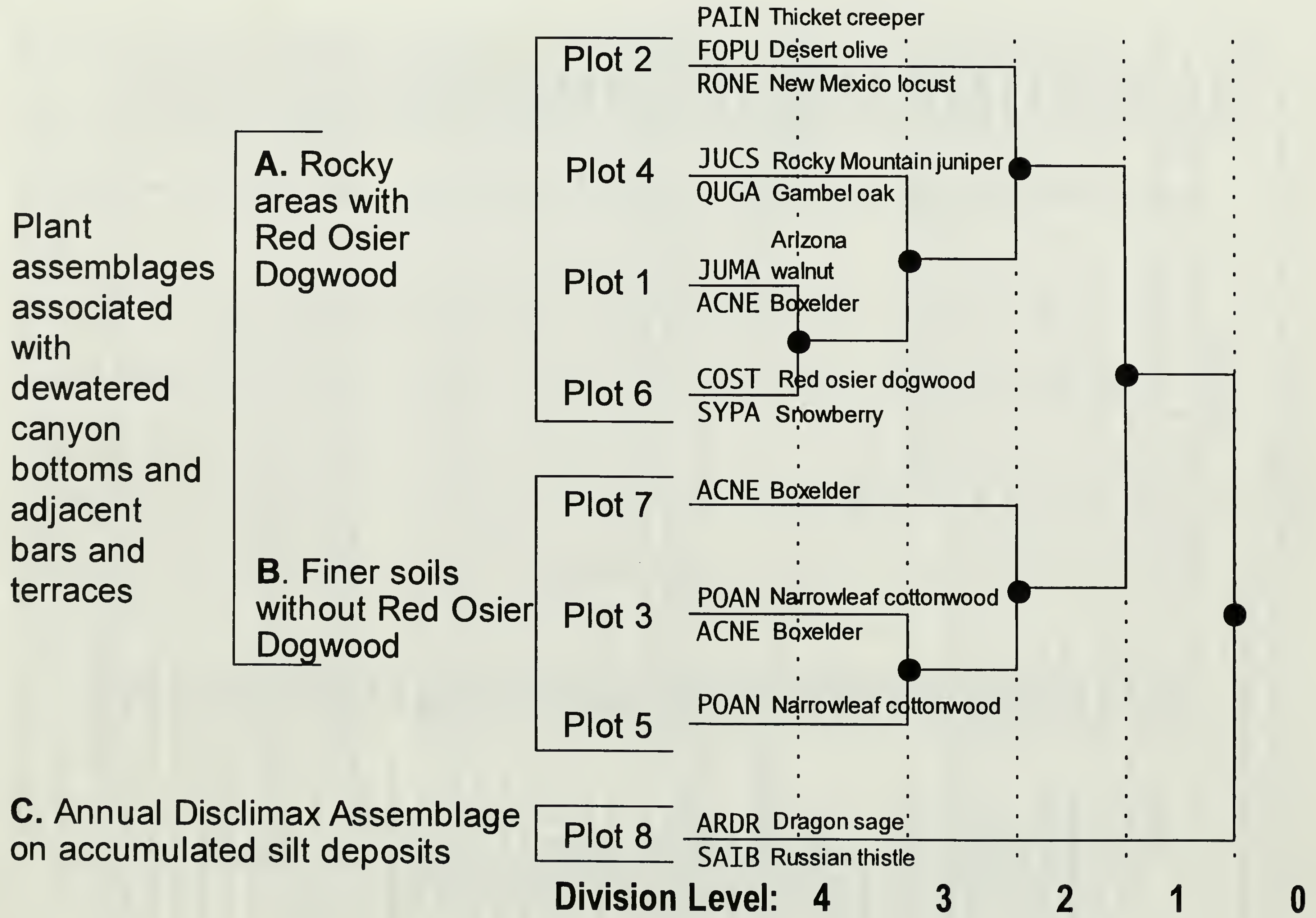


Figure 13. TWINSPAN dendrogram for "riparian" (i.e., canyon bottom) plots recorded in Walnut Canyon by Phillips (1990).

by a dense stand of desert olive, described by Little (1976) as a "thicket former."

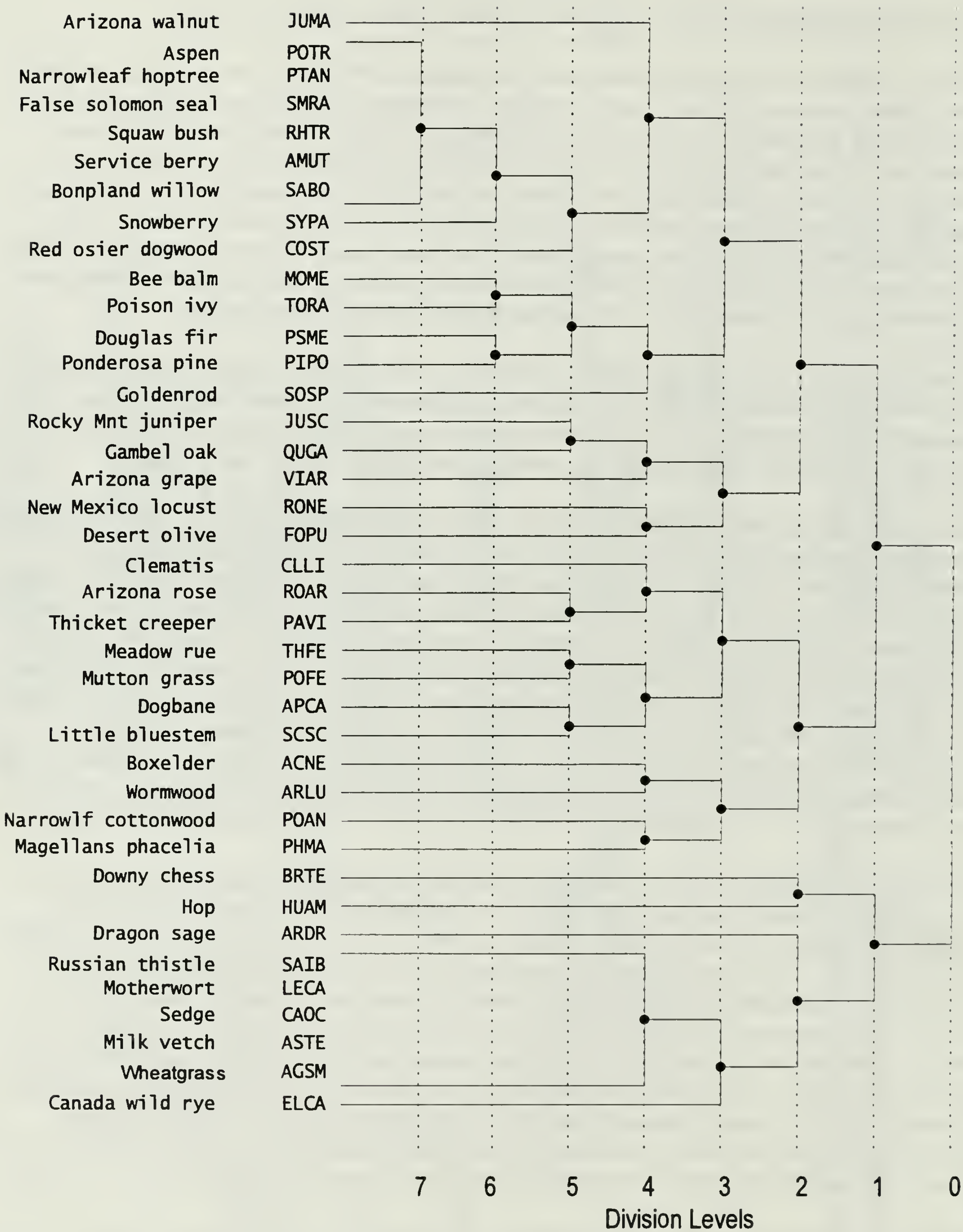
Plot 4, located about one km downstream of the visitor center, contains an abundance of upland tree species, some of which are young seedlings and saplings invading the dry stream channel as well as large Douglas fir trees over 94 cm in diameter and up to 300 years old. Such areas, therefore, had probably been moderately stable for some time prior to dam building. Also prominent among the upland trees are Gambel oak and Rocky Mountain juniper, both invader species. This small stand of upland vegetation is located on a raised gravel/rock bar and thus protected from most high-flows, most of which have been permanently eliminated by the Lake Mary dams. New Mexico locust and dogbane are also invading the dry stream bed at this site. Understory species include snowberry, dogbane, little bluestem, and bee balm.

Plots 1 and 6 are combined as a subgroup at division level four due primarily to the influence of a 20-40% cover of Arizona walnut in both plots. Plot 6 is unusual in that it contains aspen, a relatively rare species found here and points downstream. Red osier dogwood, the indicator species for the group, is particularly abundant and has invaded the dry canyon bottom.

The main unifying factor of Plots 7, 3, and 5 is the lack of red osier dogwood. Although, dragon sage occurs in Plot 6 (Cluster A), as well as Plot 8 (Cluster C), the annual disclimax plot, it comes the closest to being a differential species for Cluster B (Table 6) when it occurs at relative cover values of less than 10 %. Plots 3 and 5 combined at division level 3 and lack any upland components with the exception of less than 0.1% cover of Gambel oak in Plot 5. Plot 7 contains 0.5% relative cover of Rocky Mountain juniper at the northwest corner of the plot. On the basis of cover alone, Plots 7 and 3 are a boxelder/narrowleaf cottonwood association, but Plot 7 lacks Arizona rose, a dry canyon bottom element found in Plots 3 and 5 and moreover contains Arizona walnut and Rocky Mountain juniper which are absent in Plots 3 and 5. Alternately, one could surmise that Plots 3, 5, and 7 are boxelder/narrowleaf cottonwood associations with the latter lacking in Plot 7. Interestingly, boxelder forms a sort of gallery forest below Santa Fe

Dam. One explanation is that, although flood tolerant, this species seems to do well in a dry canyon bottom situation as long as ground water is readily available. Both boxelder and narrowleaf cottonwood are described by Phillips (1990) as being abundant throughout the length of the canyon. They are phreatophytes, requiring moist soil for an extended period of time to germinate, and can subsist on deeper soil moisture acquired through their root systems (Vines 1960). They are therefore not necessarily dependent on regular, predictable, stream flow. It is true that germination and seed dispersal of these species depends on spring runoff in many cases. However, boxelder, as discussed later in this report, appears to be surviving in WACA primarily through vegetative reproduction and narrow-leaf cottonwood is locally declining (Margaret Moore, Professor, NAU Dept. of Forestry, Personal Communication). In any case, Plots 3, 5, and 7 generally lack the dry canyon bottom and upland invader species found in Plots 2, 4, 1, and 6.

The most probable environmental factor producing the gross clustering pattern is differences in the rockiness of the substrate. Red osier dogwood was generally observed to grow on very rocky



*The original number of species was 68. Species averaging less than 0.1% relative cover across the eight plots were excluded from the TWINSPAN analysis.

Figure 14. TWINSPAN dendrogram for canyon bottom species recorded in Walnut Canyon National Monument by Phillips (1990). The common names are followed by the scientific species alphacodes.

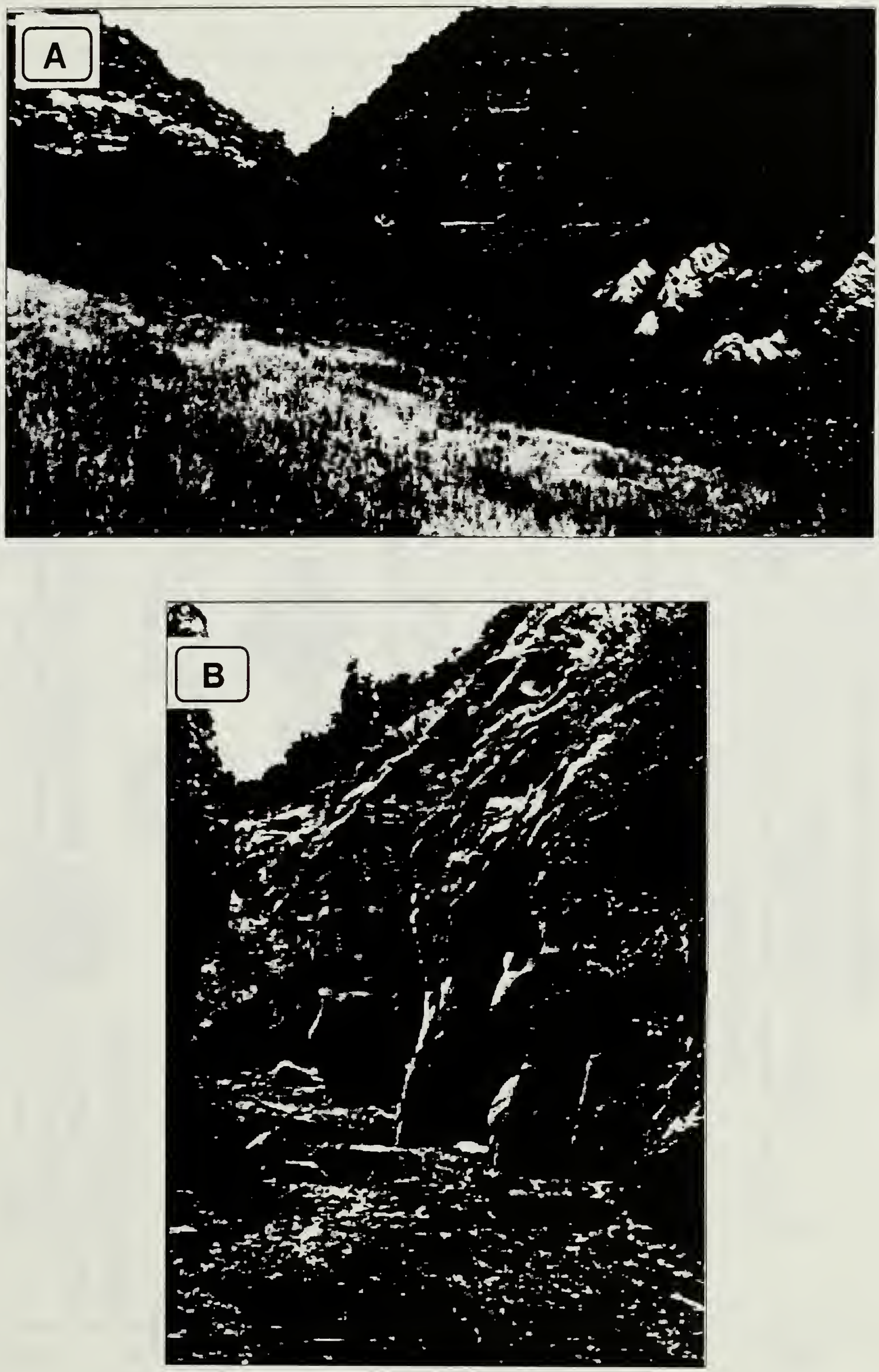


Figure 15. (A) Photograph of Santa Fe Dam from the dry reservoir bed. (B) Photograph of the "narrows" deep, scour pool filled with silt, located between Plots 1 and 2.

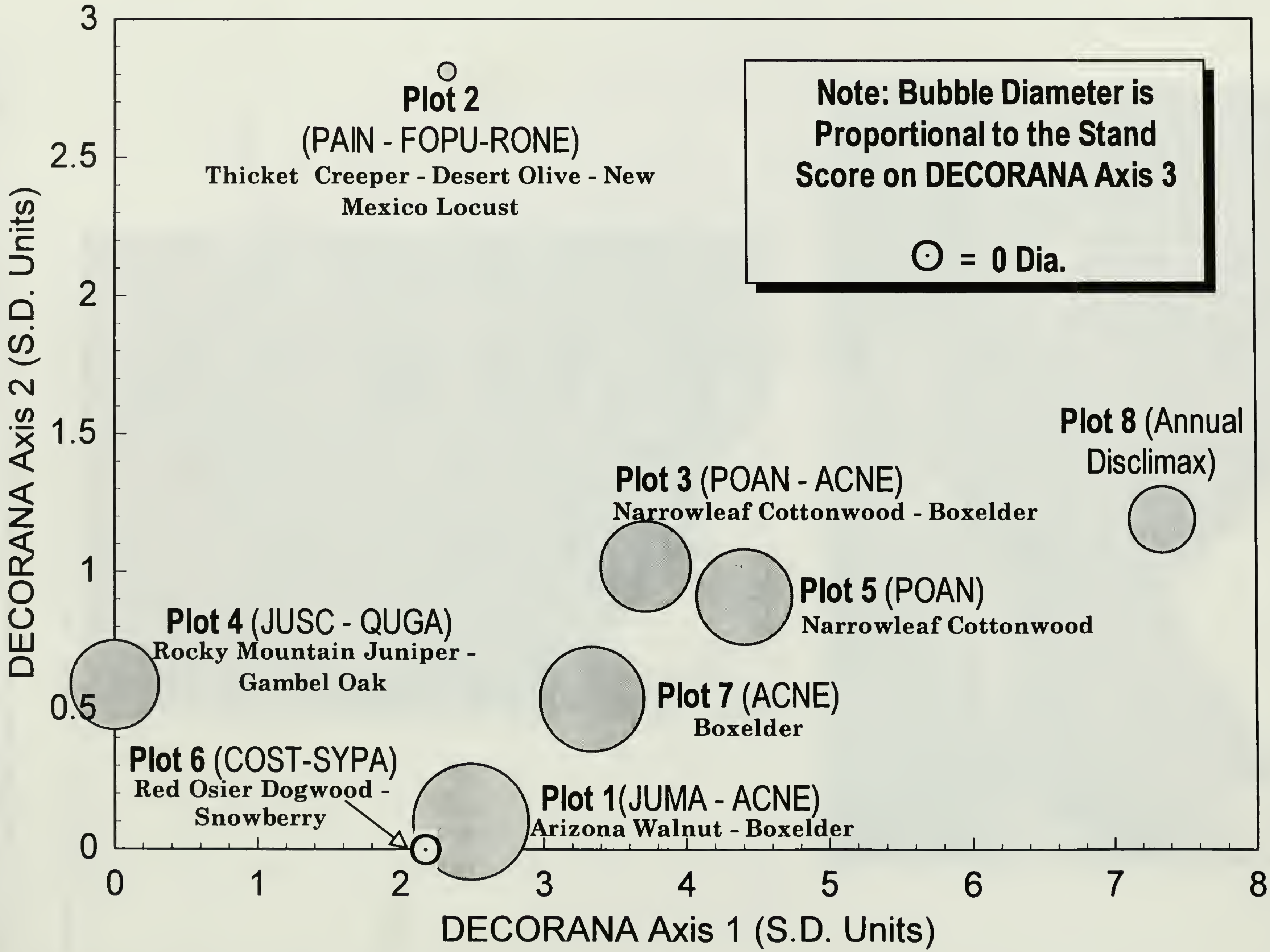


Figure 16. Detrended Correspondence Analysis (DECORANA): Walnut Canyon National Monument canyon bottom plots recorded by Phillips (1990). Species alphacodes are defined in Table 5., common names in Appenxix II,

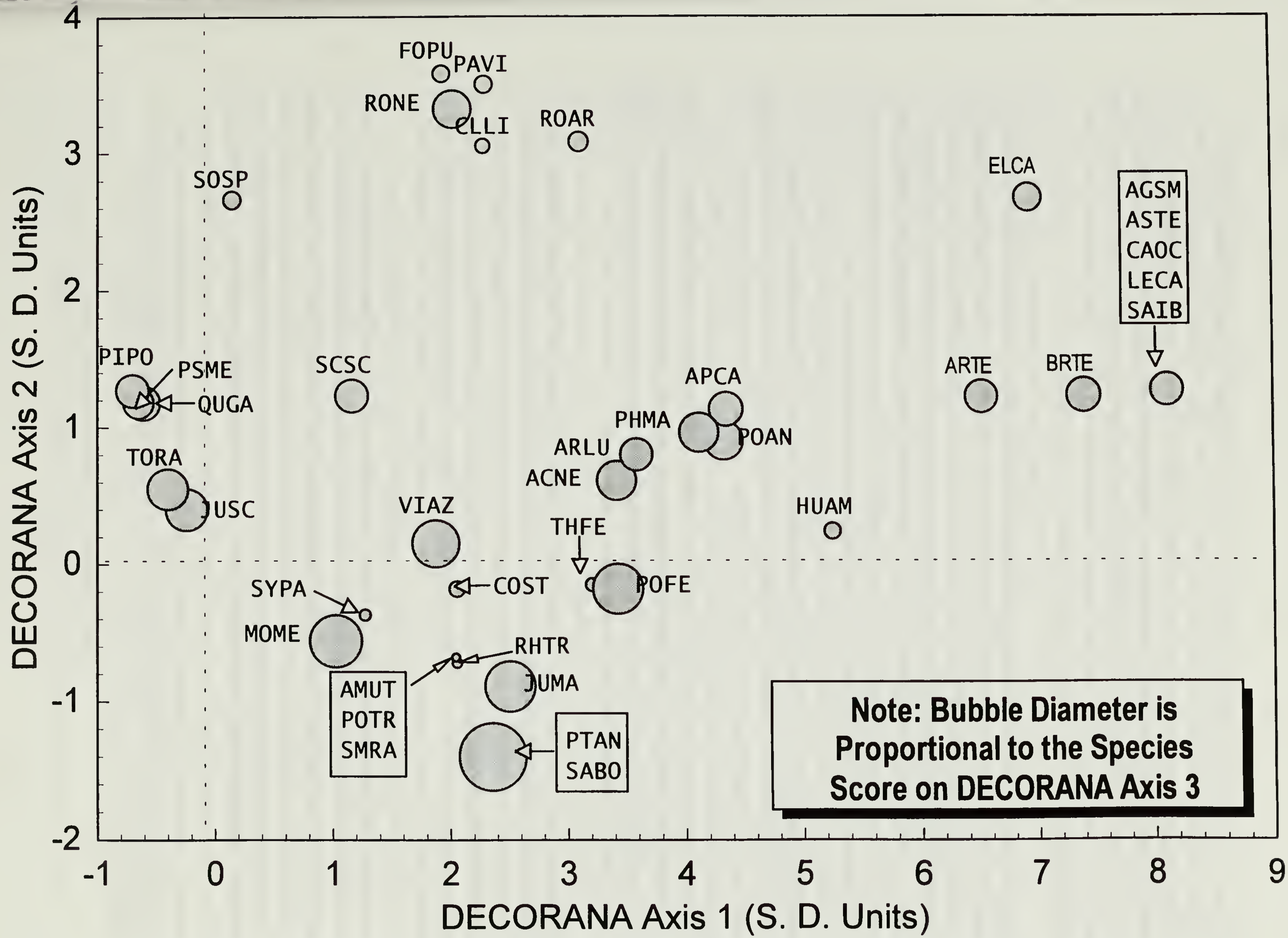


Figure 17. Detrended Correspondence Analysis (DECORANA): Walnut Canyon National Monument canyon bottom species recorded by Phillips (1990). Species alphacodes are defined in Table 6; common names are given in Appendix II.

substrates within the dry canyon bottom. The 1989 average percent rock cover for Plots 1-8 (Phillips, unpublished data) was 33%, 38%, 6%, 31%, 0%, 3%, 3% and 0% respectively. When averaged, there was approximately 14% rock cover for all plots in 1989. In comparison, the 1993-94 average percent rock cover for Plots 1-8 (data on file) was 52%, 68%, 2%, 52%, 16%, 11%, 4%, and 1% respectively. When averaged, there was approximately 26% rock cover for all plots in 1993-94. Generally, the plots became rockier after the 1993 high-flow event, but this pattern is only evident in the upper reach of the canyon by Plots 1-6.

Species. The 1989 species clustering developed by TWINSPAN is presented in Table 6 and Figure 14. The species dendrogram shows a subdivision at level one into two groups of species. The lowest group is typical of silted-in, irregularly flooded canyon bottom areas where water stands for periods of time (Figures 14A and B, and species below the double line in Table 6). The upper group consists of species typical of areas of the canyon where irregular flooding from Lower Lake Mary overflows takes the form of rapid moving water over a gravelly/rocky stream bed. Water subsides first in these areas, remaining in pools and basins.

The upper assemblage is divided at division level two into two sub-assemblages. The upper sub-assemblage contains a number of upland species including the two conifers, Douglas fir and ponderosa pine. The lower sub-assemblage contains a number of vigorously vegetatively reproducing shrubs and subshrubs such as New Mexico locust, Arizona rose, and desert olive which are also invading the canyon bottom. Regionally, these species together with a number of woody lianas, for example clematis, thicket creeper, and Arizona grape, are found more typically on the banks and slopes adjacent to active ephemeral riparian areas, but now appear to be rapidly increasing in the Walnut Canyon bottom (see below).

The lower assemblage (below the double lines on Table 6) consists of the "annual disclimax" species discussed earlier as well as downy chess, found in all plots except Plots 5 and 6, and hoptree found also in Plots 6 and 7 at low cover values. Hoptree forms a species cluster of one and TWINSPAN reveals no evident affinities of this species to any others. Dragon sage also occurs as a species cluster of one with no specific affinity to the annual disclimax assemblage even though it is a sub-dominant in Plot 8, with 40-50% cover. Except for Plot 6 it does not occur in any stands where red osier dogwood is present. The most coherent group is an assemblage of six species, aspen through Bonpland willow (Table 6, Figure 14) found only in Plots 1 and 6. Except for Bonpland willow, these are primarily upland species or species associated with terraces and banks bordering the dry canyon bottom. The other coherent cluster is an assemblage of six herbaceous species, from Russian thistle through Canada wild rye, found exclusively in Plot 8, the annual disclimax plot. Unfortunately, the lack of additional plots hinders any attempt to analyze the floristic structure of this assemblage and its interrelationships with the other assemblages. Field observation, however, reveals that this patchy, disturbance community produced by irregular flooding of silt-filled depressions exists throughout the old canyon bottom within WACA and appears to be a coherent though highly transient assemblage (Figure 15).

DECORANA Ordinations

Plots. The DECORANA stand ordination for the 1989 vegetation plots is shown in Figure 16. Axis 1[17] reveals a very strong gradient with Plot 2 occurring singly at the end of the second axis. The four large bubbles, showing close affinities on DECORANA axis 3, representing Plots 1, 3,

5, and 7 form a group with rather close affinities based on the dominance or codominance of the bottomland[18] species, boxelder and narrowleaf cottonwood. Plot 4, characterized by Rocky Mountain juniper/Gambel oak, at the beginning of axis 1, is typical of the raised gravel bar vegetation in the upper reaches of Walnut Canyon within WACA and, as revealed by the TWINSPAN analysis and field data, is the "rockiest" of the plots in terms of substrate particle size. Plot 8, an annual "disclimax" association, is located about 1 km above Santa Fe Dam and has the finest substrate particles (i.e., silt and sand). Plot 6, characterized by red osier dogwood/snowberry, shows close affinities to Plot 1 in terms of their scores on the first two DECORANA axes but they diverge from one another on the third DECORANA axis. In fact, these stands occupy the beginning and end, respectively, of DECORANA axis 3. Interestingly, Plot 2, closest to Plot 6 on DECORANA axis 3 are both shrub dominated plant assemblages in contrast to the rest of the plots which, except for the anomalous Plot 8, are dominated by tree species.

Species. The DECORANA 1989 species ordination (Figure 17) efficiently separates out the woody species of ponderosa pine, Douglas fir, Gambel oak, and Rocky Mountain juniper more typical of upland areas, from herbaceous "invader" and increaser species, such as Smith wheatgrass, *Astragalus tephrodes*, sedge, motherwort, and Russian thistle, more typical of the disturbed bottom land such as in the vicinity of Santa Fe Dam. On the second DECORANA axis, vegetatively reproducing perennial shrubs and herbs, such as New Mexico locust, clematis, Arizona rose, thicket creeper, and desert olive, which are abundant in rocky stretches of the dry canyon bottom are separated from species which are generally associated with the finer soils of elevated benches adjacent to the old channel. The later include squawbush, Arizona walnut, service berry, and Bonpland willow.

Both axes appear to be related to disturbance factors. Axis 1 is interpreted as representing a gradient along the stream channel from raised gravel bars occupied and invaded by upland species to the deep, silty, alluvial fill accumulated behind Santa Fe Dam, now a periodically flooded "weed-field." Axis 2 is interpreted as perpendicular to the first, beginning at the more stable benches adjacent to the stream channel and extending to the intermittently disturbed old stream channel. Both gradients are typified by a change in substrate from fine particulates to coarser materials, positive to negative scores on the first axis, and negative to positive scores on the second axis.

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[17] The unit of ordination length (Figures 16 and 17) may be called an average standard deviation of species turnover, or SD. A full turnover in species composition of samples occurs in about 4 SD; a 50% change occurs in about 1 SD (Gauch 1982).

[18] Bottomland species are those on low land along a river which is seldom covered by standing water.

Effects of the 1993 Lake Mary Overflow

A comparison between 1989 (pre-flood, Phillips [1990] data) and 1993-94 (post-flood, this study) importance values for primary plant species components is shown in Table 7 for all plots. After the flood, Plot 1 shows an increase in bee balm and hoptree, a decrease in downy chess and narrowleaf cottonwood, and relative stability for Arizona walnut, boxelder, and red osier dogwood. Plot 2 showed an increase in New Mexico locust, an unidentified perennial grass, red osier dogwood, and desert olive, a substantive decrease in thicket creeper and clematis, and some decrease in Arizona rose. Plot 3 showed an increase in boxelder, downy chess, mullein, and narrowleaf cottonwood, and a decrease in Arizona rose and Magellan's phacelia. Plot 4 showed an increase in Gambel oak and goldenrod, and a decrease in Rocky Mountain juniper, snowberry, and bee balm. Plot 5 showed an increase in mullein and unknown seedlings, a decrease in narrowleaf cottonwood, dragon sage, and dogbane, and removal of boxelder. Plot 6 showed an increase in Arizona rose, bee balm, and hoptree, and a decrease in clematis, goldenrod, red osier dogwood, snowberry, and starflower. Plot 7 showed an increase in Arizona walnut, boxelder, downy chess, dragon sage, and Rocky Mountain juniper, and a decrease in a sagebrush species. Plot 8 showed an increase in Russian thistle and scouring rush, a decrease in bee balm, downy chess, and dragon sage, and an increase in species which were not present in 1987 (tumble mustard, western ragweed, and Virginia creeper).

Overall, the importance values indicate a decrease in vines, such as thicket creeper and clematis; woody plants which are susceptible to damage or removal by flood waters, such as Rocky Mountain juniper, narrowleaf cottonwood, and boxelder; and an increase of disturbance indicator species, such as goldenrod, bee balm, and mullein. Importance values give trend information and as such their value should not be overemphasized. Since the value is dependent upon cover, frequency, and density, species like mullein, which do not have much cover, but whose seedlings are large in number and scattered throughout the plot, attain high importance values.

Both relative and absolute cover values for each plot yield a more realistic picture of the response of vegetation to flooding. A comparison of absolute cover (Table 8) for the pre- and post-flood plots shows the variety of response. Some species declined in some plots, for example boxelder in Plots 1, 5, and WC2, while other species increased in other plots, for example Rocky Mountain juniper in Plots 4 and WC2. Generally, the average absolute cover percentage remained similar for most species of trees and shrubs. This is shown by the little change in Gambel oak in Plots 1, 4, 5, and 7 and Arizona walnut in Plots 3, 5, 6, and 7.

Differences in absolute cover values and importance values (Table 9) for the three years of study 1973 (Joyce 1974), 1989 (Phillips 1990) and 1993 (this study) also corroborates these findings. In this table, data for the top three representative herbaceous perennials: Arizona grape, dragon sage, and the sum of grasses; the three shrub species: Arizona rose, New Mexico locust, and snowberry; and the three tree species: Narrowleaf cottonwood, Arizona walnut, and boxelder; were compared over time. Though Joyce's eight transects differed in location from Phillip's plots, similar results were found, within an order of magnitude (Figure 21). Minor differences probably reflect subjective differences among researchers. The only substantive difference may be seen in the absolute cover of boxelder and the IV for the combined grasses; Joyce's cover and

Table 7. A comparison between 1989 (pre-flood) and 1993-94 (post -flood) importance values for primary plant species for Plots 1-8.

	Plot 1		Plot 2		Plot 3		Plot 4		Plot 5		Plot 6		Plot 7		Plot 8	
SPECIES:	1989	1993	1989	1993	1989	1994	1989	1993	1989	1993	1989	1993	1989	1994	1989	1994
Arizona grape					19.93	8.52										
Arizona rose			42.64	33.67	66.22	14.38					16.37	23.62				
Arizona walnut	41.91	37.03											19.32	28.17		
Bee balm	19.59	51.54					22.84	15.54			0	29.15			23.13	3.58
Boxelder	33.77	31.65			14.82	73.7			20.07	0			19.32	100.62		
Clematis			20.93	13.4							28.51	10.78				
Desert olive			32.84	38.18												
Dogbane									39.99	14.98						
Downy chess	29.64	0			13.55	21.44							46.3	115.44	91.68	11.53
Dragon sage									79.76	22.35			8.62	27.91	77.13	9.37
Gambel oak							40.02	44.45	11.2	13.7						
Goldenrod							28.66	33.85			18.58	1.27				
Hoptree	15.72	22.64									0	20.26				
Magellan's phacelia					29.74	22.73										
Mullein					0	24.51			1.27	50.17						
Narrowleaf cottonwood	20.61	10.5			63.3	43.74			107.9	90.29						
New Mexico locust			40.03	64.79												
Perennial grass			7.67	26.72												
Red osier dogwood	26.36	27.63	23.95	28.78							54.4	32.61				
Rocky Mnt. juniper							63.47	48.29					10.79	12.79		
Russian thistle															54.8	92.27
Sagebrush													69.85	0		
Scouring rush															9.13	13.17
Sedge															14.74	0
Snowberry							28.81	22.3			60.05	40.05				
Starflower											21.74	0				
Thicket creeper			90.58	7.42												
Tumble mustard															0.34	21.02
Unknown seedling									0	28.87						
Virginia creeper															0	12.6
Western ragweed															0	106.84

Table 8. A comparison of 1989 pre-flood and 1993 post-flood absolute cover, frequency and density for trees (and some shrubs) by study plots at Walnut Canyon National Monument. (Plots 1-8, 1989 data from Phillips (1990), plot WC2 plot, 1988 data from Jenkins et al. (1991).

PLOT/Species	Absolute Cover		Absolute Frequency		Absolute Density	
	1989	1993	1989	1993	1989	1993
PLOT 1						
Boxelder	20%	15%	100%	100%	4	4
Arizona walnut	26%	40%	100%	33%	19	12
Rocky Mountain juniper	7%	4%	100%	66%	7	2
Narrowleaf cottonwood	7.3%	5%	100%	33%	4	2
Hoptree	2.8%	3%	100%	100%	21	5
Gambel oak	0.2%	Trace	33%	33%	3	1
New Mexico locust	2.4%	5.7%	33%	33%	3	3
Bonpland willow	0.8%	3%	33%	66%	4	6
PLOT 2						
New Mexico locust	18.84%	27.1%	66%	100%	7	132
Red osier dogwood	8.16%	5.1%	24%	66%	13	15
Boxelder	9.3%	8%	33%	33%	1	1
Gambel oak	0%	0%	33%	0%	1	0
PLOT 3						
Narrowleaf cottonwood	0.15%	8.4%	100%	100%	23	40
Boxelder	22%	28.4%	100%	100%	9	7
Arizona walnut	0%	1.1%	0%	33%	0	1
PLOT 4						
Gambel oak	16.6%	17%	100%	100%	163	110
Ponderosa pine	0.6%	0.6%	66%	66%	4	3
Rocky Mountain juniper	37.2%	25.7%	100%	66%	14	10
Douglas fir	10.1%	14.7%	33%	66%	9	8
Boxelder	0.1%	0%	66%	0%	2	0
PLOT 5						
Narrowleaf cottonwood	55%	46.7%	100%	100%	125	97
Boxelder	6.7%	1.7%	33%	0%	5	0
Gambel oak	0.1%	0.7%	33%	66%	1	5
Boxelder	0%	Trace	0%	33%	0	2

Table 8. Continued.

PLOT/Species	Absolute Cover		Absolute Frequency		Absolute Density	
	1989	1993	1989	1993	1989	1993
PLOT 6						
Boxelder	9.6%	12.0%	33%	33%	1	2
Arizona walnut	10.0%	9.0%	33%	33%	2	2
Douglas fir	0.2%	Trace	0%	0%	0	0
Aspen	3.2%	3.1%	66%	66%	11	17
Narrowleaf cottonwood	0%	0.01%	0%	33%	0	1
PLOT 7						
Boxelder	64.5%	74.24%	100%	100%	13	5
Gambel oak	Trace	0%	33%	0%	2	0
Arizona walnut	7.4%	11.4%	33%	66%	1	3
Rocky Mountain juniper	0.5%	4.3%	33%	33%	1	1
PLOT 8						
No trees or shrubs	-	-	-	-	-	-
PLOT WC2[1]						
Boxelder	13%	4%	-	66%	2	2
Rocky Mountain juniper	13%	6.3%	-	100%	4	8
Gambel oak	3%	6.3%	-	100%	14	80
Ponderosa pine	3%	6.3%	-	33%	1	1
Squawbush	3%	2%	-	33%	1	1

[1] Data for absolute frequency values not available for this data set.

Table 9. A comparison between 1973 (Joyce), 1989 (Phillips), and 1993-94 (this study) averaged absolute cover percentages and averaged importance value percentages for all plots.

	Average Absolute Cover %			Average Importance Value %		
SPECIES:	1973	1989	1993-94	1973	1989	1993-94
Understory Species:						
Dragon sage	2.17	2.57	2.17	16.14	21.6	9.16
Combined grasses	7.37	0.78	5.14	86.64	35.65	33.68
Arizona grape	1.57	2.08	3.89	5.38	6.34	3.91
Shrub Species:						
Snowberry	0.69	3.23	0.88	2.05	11.28	7.86
New Mexico locust	6.31	2.1	0.79	15.51	6.26	9.77
Arizona rose	4.66	2.78	3.43	12.52	17.08	11.11
Tree Species:						
Boxelder	29.49	16.5	17.41	32.51	32.47	30.89
Arizona walnut	19.22	5.4	7.68	19.79	9.91	12.69
Narrowleaf cottonwood	11.35	9.66	7.53	14.01	21.44	19.23

importance values were almost double for boxelder, about three times greater for the grasses. This is most likely a result of the difference in plot locations. Joyce's four eastern plots were below Santa Fe Dam where a gallery forest of boxelder exists and Joyce's line intercept method would tend to document the cover of grasses more precisely. Interestingly, the comparison species appear to be in equilibrium with the periodic runoff events, neither gaining nor losing cover over the last 20 years during which there have been four non-summer high-flow events during 1979, 1980, 1983, and 1993 and a 1987 summer high-flow event.

The low cover of Bonpland willow and arroyo willow and the absence of hydrophytes throughout the corridor of Walnut Canyon is a direct result of the lack of flowing water. Only those obligate riparian species which can inhabit areas below or at seeps or are dependent upon locations where slope runoff is channeled can survive. Otherwise, the canyon bottom vegetation more closely resembles an upslope or terrace, not a true riparian plant community. Few areas throughout WACA's canyon bottom are open. Annual disclimax vegetation occurs on areas of deep silt. Sandy areas are carpeted with dogbane, perennial grasses, and mullein, while rocky areas are choked with New Mexico locust, Arizona rose, red osier dogwood, and boxelder. Apparently, high-flow events to date do not last long enough to kill plants in the stream corridor by inundation and submergence, nor do they completely scour the bed and remove all woody species.

General Effect of High-flows on Vegetation

The impact of water flow in Walnut Canyon varies depending on whether the flow is during the dormant, winter season or during the active growing spring and summer seasons. The effect of flooding on bottomland species is greatly influenced by five, critical factors: time of year, flood frequency, flood duration, water depth, and siltation (Teskey and Hinckley 1977, Malanson 1993). It has been shown that flooding can increase the growth rate of most tree species, especially bottomland species, if trees are flooded during the dormant season and if the flood water recedes before growth begins in the spring (Broadfoot 1967, McAlpine 1961). When dormant, tree roots have a low requirement for oxygen and exhibit little or no growth (Yelenosky 1964). After flooding and the dormancy are over and active growth returns, increased growth rates are attributed to higher soil moisture levels (Broadfoot 1967). This is particularly evident in areas which are subject to drought stress, as flooding during the dormant season increases soil moisture during the growing season. Soil moisture is responsible for an increase in radial growth of approximately 50% for most bottomland species (Broadfoot 1967). Conifers are reported to benefit from flooding early in the year (Burton 1972).

The effect of flood frequency on growth rates has not been clearly demonstrated. However, understory vegetation is strongly influenced by flooding, with an increase in herbaceous species diversity as flood frequency decreases (Bell 1974). The impact of flood duration is closely related to the flood tolerance of the species. Obviously, some damage does occur with high-flows of short periods (less than one month) while long-term flooding results in higher mortality (Teskey and Hinckley 1977). Water depth impacts gas exchange through lenticels and has more deleterious impact on seedling and herbaceous species. Siltation increases dieback and reduces stem height and diameter (Kennedy 1970).

The Effect of High-flows on Vegetation at Walnut Canyon National Monument

Four substrates associated with vegetative types can be reasonably discerned: (1) irregularly flooded, silty substrates having considerable amounts of boxelder and sometimes narrowleaf cottonwood and an annual disclimax assemblage of short lived weedy perennials and herbaceous plants; (2) a raised, rocky, dry canyon bottom assemblage which is dominated by red osier dogwood, (3) rocky, raised alluvial deposits often forming "islands" in the bottom of the dry stream channel with vigorously resprouting species such as Arizona rose, New Mexico locust, and some invading upland species such as Rocky Mountain juniper and Gambel oak; and (4) a rocky, terrace upland vegetation assemblage of upland tree and shrub species such as ponderosa pine, Douglas fir, Gambel oak, squaw bush, snowberry, etc.

The old, dry canyon bottom assemblage consists of a great many shrub, subshrub, and woody liana species. Many of these species such as New Mexico locust, Arizona rose, and red osier dogwood are active resprouters while an associate, desert olive is a thicket former (Little 1976). In any case, these shrubs typically occupy slopes and other rocky/gravelly areas adjacent to the main stream channel in similar undammed drainages such as the upper reaches of the West Fork of Oak Creek Canyon (see Comparison Canyons section, below). The dewatering of the Walnut Canyon drainage appears to have encouraged invasion of these species into the abandoned stream channel. Judging from hydrological data documenting Lower Lake Mary over flows, such events have not occurred with either sufficient intensity and frequency to eliminate these invaders. Several woody lianas, including Arizona grape, thicket creeper, and clematis and the trees: boxelder and narrowleaf cottonwood, are important associates of this assemblage.

Floristic Comparisons

A floral list for WACA was prepared by compiling five previously published species lists[19] (Arnberger 1947, Spangle 1953, Joyce 1974, Phillips 1990, Jenkins et al. 1991). Based upon the compiled floral list, a total of 406 species, or 349 species plus 57 infraspecific taxon, in 69 families are known from WACA. Previously, 326 species in 62 families had been reported (Joyce 1976).
It was outside of the scope of this report to verify each species by inspecting voucher specimens and/or to resolve any conflicts between the separate lists. The exact numbers of families and species should not be overemphasized as taxonomic groupings and divisions change with time. Over the past 46 years, there have been numerous nomenclatural changes, with some species being combined, others split into two species or infraspecific taxa. It may be noted that Spangle (1953) did not publish a revised checklist (as the title of his paper suggests). Rather, he noted 75 additions to Arnberger's 1947 species list. Also, Phillips' (1990) list is for her "riparian" community only and does not include upland species. It is apparent that Jenkins et al. (1991) omitted Joyce's 1974 species list in compiling their list of vascular species.

Some of the canyon bottom species may no longer be present at WACA. For example, the native, perennial herb, marsh smartweed (*Polygonum coccineum*), is a facultative wetland or aquatic plant, often spreading into upland habitats adjacent to wetlands (Larson 1993). In the

[19] The floral list is on file at our office.

Flagstaff area, it is commonly found along Upper and Lower Lake Marys and Mormon Lake. The species was last collected in WACA "in a pool in the stream bed" by H.F. Hastings on 18 August 1949 (Phillips 1990 and Jenkins et al. 1991). This species has not been collected in WACA since that date, based upon a search of the herbariums at Northern Arizona University and WACA, nor did we encounter it during our field work.

Comparison Canyons

West Fork of Oak Creek Canyon

Of the comparison canyons which were visited, the upper reach of the West Fork of Oak Creek (WFOC) [T19N, R5E, Sec. 10 and 15; Elev. 2012 m; USGS Dutton Hill Quad] had the greatest physiographic similarity to Walnut Canyon. The area does have similar precipitation of 432 to 660 mm per year and geology with basalt overlying Paleozoic rocks of the Kaibab Formation, Toroweap Formation, Coconino Sandstone, Supai Formation, and Redwall Limestone (Aitchison 1978).

Four Braun-Blanquet relevés (Table 10) were performed along a 1.0 km reach of the stream bottom in an area which bore a great deal of physiographic and geological resemblance to Walnut Canyon with Kaibab Limestone on the canyon rim and Coconino Sandstone making up the bedrock of the canyon bottom and adjacent steep cliffs. The stream bed (Figure 18A) is composed of rounded sandstone and basalt rocks and boulders (40-90% of the bed's surface), gravel (10-50%), sand (<1%) and negligible amounts of silt and smaller size particles)[20] At the times of our visitations: 11 November, 1993 and 7 July, 1994 the creek was not flowing. However some small, shallow pools were visible; the remnants of a recent summer rain. In the upper reach it appeared that flow was dependent upon seasonal winter runoff and summer thunderstorms. The entire WFOC drainage basin covers about 140 km^2. The lower portion of the WFOC, where it confluences with the mainstem is a permanent stream with an average flow, augmented by three springs, estimated at < five cfs (Donald Bills, Hydrologist, USGS Water Resources Division, Flagstaff, AZ, personal communication, 1994). No other hydrological information was available; the drainage has never been gaged

The dominant overstory tree species where the relevés were performed were ponderosa pine and Engelman spruce; the dominant shrub understory was comprised of willow species and New Mexico locust; other plant associates included red osier dogwood, narrowleaf hoptree, Arizona rose, Gambel oak, and mullein (Table 10). The most noticeable differences between the vegetation composition of the stream channel vegetation in the WFOC and Walnut Canyon is a much higher average cover of willows (*Salix* spp.) and red osier dogwood in the former and a noticeably lower cover of boxelder, narrow-leaf cottonwood and New Mexico locust in the latter.

Because of the irregular flooding and drought within Walnut Canyon, we surmise that willows can no longer compete with more aggressive shrubby increaser species along the stream channel.

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[20] Silt: $\leq$ 0.05 mm ϕ; Sand: >0.05 - 2 mm ϕ; Gravel: >2 mm - 7.5 cm ϕ; Rock: >7.5 - 19 cm ϕ; Boulders: >19 cm ϕ

Table 10. A comparison of Braun-Blanquet relevés for important plant species at West Fork of Oak Creek, Fry, and Walnut Canyons. The ten most important, persistent, perennial plant species in terms of absolute ground cover, at Walnut Canyon are compared with two nearby undammed drainages at approximately the same elevation (±2,000 m). Data from the two comparison canyons consists of the average Braun-Blanquet cover classes[1] recorded in four vegetation relevés (Mueller-Dombois and Ellenberg 1974, Bonham 1989). Relevés were ±400 m^2 and established along approximately 1 km reaches of both channels. Walnut Canyon data were derived from ground-cover data collected by Phillips (1990). Percent cover data were converted to Braun-Blanquet Cover classes for comparison.

Plant Species	West Fork of Oak Creek Canyon	Fry Canyon	Walnut Canyon
Arizona Grape	P[2]	2.5	1.0
Arizona rose	1.0	0.8	1.0
Arizona walnut	∅[3]	∅	2.0
Bee balm	P	0.6	P
Big-tooth maple	∅	0.8	A[4]
Boxelder	0.8	2.0	2.0
Combined perennial grass cover	P	P	1.0
Dogbane	0.3	∅	P
Douglas fir	1.3	∅	P
Dragon sage	∅	P	1.0
Gambell oak	0.3	1.0	P
Narrow-leaf cottonwood	∅	∅	2.0
New Mexico locust	0.3	1.3	1.0
Poison ivy	P	0.8	P
Ponderosa pine	P	1.3	P
Red osier dogwood	1.5	∅	P
Snowberry	∅	∅	1.0
Virginia creeper	P	1.0	P
Wax currant	0.3	∅	∅
willow, Gooding	0.3	∅	∅(A?)
willow, Bonpland	2.5	P	P

1 5: >75%; 4: 50-75%; 3: 25-50%; 2: 5-25%; 1: 1-5%; 0.1: <1%

2 Present in plots or relevés but not in the top ten in terms of perennial ground cover

3 Not encountered in plots or relevés; locally absent (i.e., from this particular reach of the stream channel) but present i n broader local species lists.

4 Apparently absent from drainage

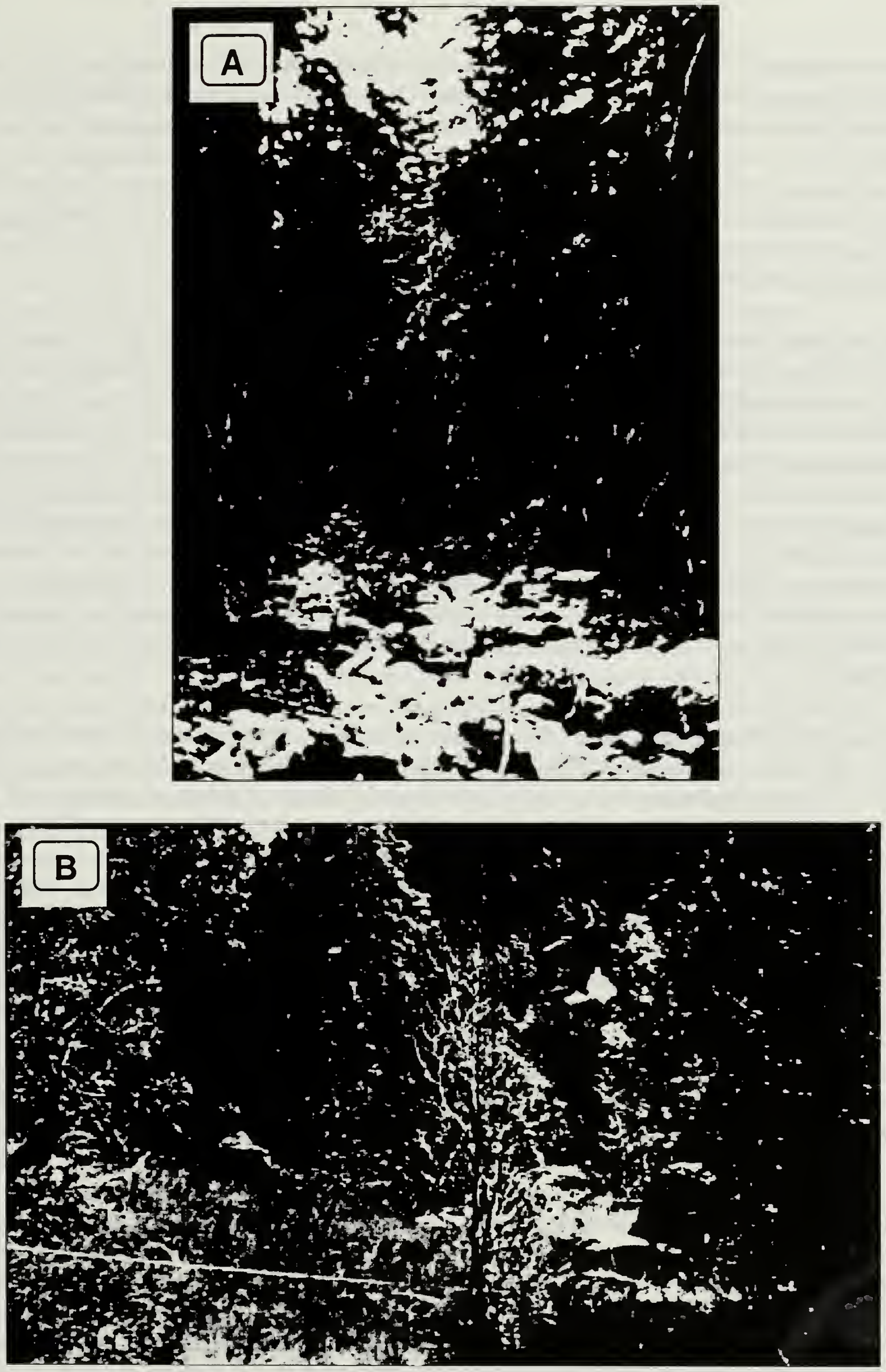

Figure 18. (A) Photograph of the upper reach of West Fork of Oak Creek Canyon. (B) Photograph of the canyon bottom at Walnut Canyon National Monument.

Even though the WFOC is an ephemeral stream, it is undammed and apparently it flows regularly enough during summer monsoon and spring snow-melt runoff to support a healthy stand of willows. Red osier dogwood appears to favor rocky substrates within and adjacent to stream channels (see above). The irregular flooding of Walnut Canyon has resulted in large accumulations of silt in old "pool" areas and also for some distance above Santa Fe dam (Figure 15A). This may have diminished the available habitat for dogwood relative to undammed drainages in the area. In other words, dogwood may have been even more important in the pre-dam Walnut Canyon drainage.

Not only is the cover of boxelder lower in the WFOC than Walnut Canyon, but its growth form is different. The largest boxelder tree found in the upper reach of the WFOC drainage was 28.1 cm dbh. This was an old, upright trunk located almost in the center of the stream bed. It had been dead for some time and was surrounded by a debris pile about 1.5 m high and 3 m broad and a large number of basal resprouts up to four m high. The next largest tree was 23.0 cm dbh, but the center of the trunk was rotten and the tree appeared to be dying. The largest healthy individual was approximately 16.6 cm in diameter. In comparison, in Walnut Canyon, live boxelders greater than 30 cm dbh are not uncommon and a few live individuals greater than 40 cm have been observed. Most boxelder in both Fry Canyon and WFOC canyon were less than 15 cm dbh and were ramets, the products of vegetative reproduction. As in Walnut Canyon, true seedlings were rare; none were observed in any of the four relevés performed in each of Fry Canyon and the WFOC.

Boxelder in Fry Canyon and the WFOC were more shrubs than trees in growth form. Elmore (1976), describing this plant in the Southwest, refers to it as a medium-sized tree but "more often than not it is a many-stemmed shrub of 10 to 15 feet (3-4.6 m)." Elsewhere in the west, it is described only as a small to medium sized tree 12-15 m high (Little 1976, Lanner 1984). However, boxelder is a known basal resprouter in response to high-flows, and, to a lesser extent, from fire (Harper et al. 1992) and occasionally develops large burls (Lanner 1984). Malanson (1993), in a review of the literature, states that boxelder is one of several species which shows increases in establishment and growth, due to dam-induced decreases in flooding, at the expense of cottonwood which exhibits declines. Moreover, Malanson (1993) in a study of hanging gardens in southern Utah described boxelder as being more prominent on the rarely flooded sites. The lack of regular flooding in Walnut Canyon may have allowed this species to develop into more of a "gallery" tree component by eliminating regular flooding which removes small trees and enhances resprouting due to flood damage. This habit is even more pronounced below Santa Fe Dam in Walnut Canyon where boxelder forms a true gallery forest as described in Joyce (1974).

In the WFOC canyon stream bottom, we also noted that large individuals (1-2+ m) and dense growth of New Mexico locust were for the most part restricted to terraces adjacent to and above the stream bed. This is the normal habit of this upland large shrub or small tree (Little 1976). In the stream bed, this species was sparse and low-statured (generally < 1m). Apparently any seedlings that become established in the dry stream bed are removed or killed or perpetually damaged and weakened by frequent or seasonal flooding events. In contrast, the dewatered Walnut Canyon drainage (Figure 18B) has become extensively overgrown with this species over

much of its reach, particular in rocky, bouldery areas of the old stream bottom. Exceptions are silted-in areas such as depressions (formerly "pools" or "scour holes") in the channel where it, along with other woody species, are replaced by annual herbs and perennial forbs, many of these introduced species (see above).

Fry Canyon

Fry Canyon (T19N, R6E, Sec. 2 an 3; Elev. 1986 m; USGS Dutton Hill and Mountainaire Quads), visited on July 6, 1994 is a small, partially incised, east-west running canyon approximately 16 km SSW of Flagstaff. The drainage area is approximately 40-50 km2 as estimated from USGS 7.5' topo maps and the canyon bottom supports a relatively small ephemeral stream. No water was present at the time of survey. The drainage channel is dominated by rocks and boulders (40-90% of the bed's surface), gravel (10-50%), sand (<1%) and negligible amounts of silt and smaller size particles). The drainage has never been gaged. No hydrological information and data are available. There was evidence of light to moderate livestock grazing at this site.

Four Braun-Blanquet relevés summarized in Table 10 were performed along a 1.0 km reach of the stream bottom. Dominant overstory trees included ponderosa pine and Gambel oak which overtop the stream bottom, though most are rooted on the banks. Boxelder (5-25% cover) was a dominant, but, like WFOC and unlike Walnut Canyon, not in the tree layer. Plants were shrubby in habit, the result of repetitive resprouting. The largest individuals were less than 5 m high; most were 2 - 4 m. New Mexico locust was prevalent (1-5+% cover) in the stream bed but not overwhelmingly so and never exceeded 2 m in height; most individuals were 1- 2 m high. The ground layer was dominated by Arizona grape (25+% cover), with substantive cover contributions (1- 5%) by thicket creeper and poison ivy (1- 5%).

Species such as Arizona walnut, narrow-leaf cottonwood and snowberry, relatively important in the Walnut Canyon bottom vegetation, are not prevalent associates either in Fry Canyon or the upper reaches of the WFOC, although both species do occur within these drainages. Snowberry is a thicket-forming increaser species, so its prevalence in the disturbed Walnut Canyon stream bottom and absence in Fry and WFOC is explainable. The absence, or at least very low importance, of walnut and narrow-leaf cottonwood from the latter two sites cannot be explained without further investigation into habitats and species requirements. Perennial grasses, prevalent in the bottom of the Walnut Canyon drainage, are sparse in the Fry Canyon and WFOC stream bottoms. No equivalent of the annual disclimax community defined by Phillips (1990) in Walnut Canyon was observed along the reaches of Fry Canyon or WFOC examined.

Big-tooth maple, another resprouter after damage due to flooding as also observed by Harper 1992) was prominent in Fry Canyon. It was present, but not sampled in WFOC and is altogether absent from Walnut Canyon. Its growth form was entirely shrubby, resembling boxelder at this location, and not at all tree-like. This observation is corroborated both in Elmore (1976) and Lanner (1984) who state that this plant, may exhibit a variety of growth forms ranging from medium-sized shrub to tree. Whether or not this species was present in the Walnut Canyon drainage prior to its damming is unknown.

Padre Canyon

Padre Canyon (T19N, R10E, Sec. 10; USGS Ashurst Lake Quad) was visited on June 3, 1993. We hiked approximately 1.0 to 1.5 km downstream from the head of the canyon. At <2100 m, this U-shaped stretch bears little physiographic resemblance to the deeply incised box canyon of WACA at a similar elevation. In upper Padre Canyon, water from Ashurst spring was present in the steam bed intermittently and was flowing very slowly (estimated at << 1 cfs). The open, boulder-strewn canyon bottom indicates, however, that heavy seasonal flows (monsoonal and snowmelt) do occur on a fairly regular basis. Gambel oak and ponderosa pine dominate the overstory. Understory vegetation consists of serviceberry, Arizona rose, dogbane, species of willow, Arizona grape, Missouri iris, poison ivy and snowberry. Prominent perennial grasses include blue and sideoats grama.

A stream survey (Bemer 1990) of lower, more incised, V-shaped reaches of Padre Canyon at approximately 1800-1900 m described an overstory dominated by Gambel oak, Rocky Mountain juniper, ponderosa pine and Arizona walnut with occasional aspens. Understory shrubs included fernbush, cliffrose, four-wing saltbush, New Mexico Locust, squawbush, wax currant, Fremont barberry, Apache plume and peach-leaf willow. Arizona grape dominated the ground-layer. Blue grama was the dominant perennial grass.

All the above species are present at Walnut Canyon. The most noticeable difference between the vegetation of two canyon bottom is the greater preponderance of willow species in Padre Canyon and the more open nature of the stream channel. As in Fay Canyon and the WFOC Canyon, and unlike Walnut Canyon, the stream bottom is never choked by vegetation which, even if thick in places, can be bypassed without leaving the channel proper.

Mormon Canyon

Mormon Canyon (T19N, R9E, Sec 10, Elev. 2100 m, USGS Ashurst Lake Quad) was also visited on June 3, 1993 and was very similar to Padre Canyon both physiographically and vegetationally. We hiked 1 to 1.5 km down the drainage. Like the upper reach of Padre Canyon, Mormon Canyon at this elevation is more or less U-Shaped and physiographically very unlike Walnut Canyon. Like Padre Canyon this drainage is cut into the lava capped Anderson Mesa. Though no water was observed, the drainage is ephemeral, dependent upon snow melt and local thunderstorms. The following species were noticed within the drainage bottom: Gambel oak and ponderosa pine comprised the tree overstory with an occasional one-seed juniper; Utah serviceberry contributed to the shrub layer; the ground layer was dominated by Arizona rose. No willows or other obligate riparian species were observed at Mormon Canyon.

Sycamore and Volunteer Canyons

The upper reaches of Sycamore and Volunteer Canyons were not accessible due to very steep, high cliffs bordering the drainage, however existing data were available from both these areas (Schilling 1980). Upper Sycamore Canyon shares many of the dominant species with Walnut Canyon (narrowleaf cottonwood, Douglas fir, Gambel oak, red osier dogwood, poison ivy,

thicket creeper, and Richardson's brome). Interestingly, Schilling does not discuss, or even mention, willow species and their importance to the vegetational composition of the Sycamore Canyon riparian community. Nevertheless, two species of willows (Bonpland's and Scouler's) are listed in the checklist of riparian species which Schilling (1980) provides in his thesis. The growth habits of willows in Sycamore Canyon is probably similar to those in Volunteer Canyon as described below. He also describes and lists the presence of true riparian, hydrophilic, species not found at Walnut Canyon, such as broad-leaved cat-tail (*Typha latifolia)* and yellow pond lily (*Nuphar luteum* ssp. *polycepalum)* (Schilling 1980).

Volunteer Canyon (a tributary to upper Sycamore Canyon) shares many of the dominant species with Walnut Canyon (Douglas fir, ponderosa pine, red osier dogwood, boxelder, Rocky Mountain juniper, willow species, and meadow rue) but does not have the aquatic species, listed above, that were found in Sycamore Canyon (Schilling 1980). In Volunteer Canyon, "willows were found near scattered pools of semi-permanent water forming dense thicket-like tangles along the rocky drainage (Schilling 1980)."

Age and Size Distribution of Important Canyon Bottom Trees

The results of the canyon-bottom tree survey in WACA are presented in Table 11 and Figure 19. Six tree species were encountered within ten, randomly spaced 240 m^2 rectangular plots (total =0.24 ha). All of the plots were located in canyon bottom areas which were fully inundated (up to 3 m deep judging from the height of debris on the larger trees) during the 1993 high-flow through Walnut Canyon. One of the ten plots occurred in a broad, rocky area of the stream bed about 0.5 km west of the Third Island Fort. The area was occupied by a thicket of New Mexico locust and contained no trees whatsoever. The most important tree species occupying the canyon bottom were boxelder, Arizona walnut, Rocky Mountain juniper and Gambel oak . Size classes were divided into diameter increments of 5 cm except for the first or seedling class which was ≤ 1 cm. Only one Douglas fir individual, a seedling, was sampled within these plots. As mentioned earlier, its distribution in the canyon bottom is somewhat patchy, occupying small, raised gravel bars within the channel or rocky debris flows. Twenty-nine narrowleaf hoptree individuals were also encountered, occurring within three of the ten plots. Twenty-three of these individuals were in the seedling size class. The other three were in the 1.1 - 5.0 cm class, the largest of these being 3.5 cm dbh and less than three m high. This species is considered a minor understory component at best. Narrowleaf cottonwood was not present in the random sampling of this reach of the canyon. Based upon our plots and personal observations, this species may not be as prominent in WACA as Phillips (1990) otherwise seems to indicate. According to Dr. Margaret Moore (NAU Dept. of Forestry, Personal Communication, 1994), narrowleaf cottonwood is in a state of decline throughout most of the drainages in the Flagstaff region due to damming and water withdrawals disturbing normal instream flow dynamics.

Boxelder

As expected, boxelder was the dominant tree encountered in 90% of the plots and ranged in size from seedling to 31.3 cm dbh (one individual). Larger trees (>40 cm dbh) in unsampled portions of the canyon bottom have been observed. Seedlings of this species are apparently rare.

Only one seedling, or about 1.6 % of the total stems encountered, was found after surveying a total of 0.24 ha. This is far less frequent than any of the other major canyon bottom tree species. The modal class for alive and erect trees was the 10.1-15.0 cm size class.

Completely dead trees were most abundant in the preceding size class (5.1-10 cm). Dead trees were not encountered in the seedling or sapling class or in classes greater than 25 cm. These data should be interpreted in light of the fact that the 1993 high-flow may have carried away an unknown number of already dead boxelder "carcasses" and previously dead or damaged trees. A large proportion of trees ($\approx$28%), though toppled by the high-flow or otherwise severely damaged, were vigorously resprouting from the base. Dead and damaged trees were restricted in this survey to individuals larger than 5 cm dbh and smaller than 25 cm dbh. All the trees sampled, other than the seedling class, and which were not completely dead, were resprouting to some extent. In many cases, resprouting was extensive, as is the habit of boxelder (see section on comparison canyons). Due to the rarity of boxelder seedlings, we believe that this species is largely maintaining itself in Walnut Canyon by vegetative reproduction and that the curtailment of flooding frequency is allowing this species to attain fairly large size. Indeed, below Santa Fe dam at the east end of the monument, where high-flows are even more restricted, this species forms a small gallery forest. This differential response of boxelder, in terms of growth form, to flooding may prove a valuable indicator of flood frequencies and intensity in southern Colorado Plateau drainages.

We have no data to show whether or not boxelder, in Walnut Canyon, is habitually a poor seeder or whether its apparent lack of success in germination and establishment is related to the damming of the drainage. Other workers (Vines 1960, Maeglin and Ohmann 1973) suggest that, under the proper conditions, boxelder propagates well by seed. Perhaps regular flooding, now curtailed in Walnut Canyon is necessary to maintain seedling growth and establishment. We expected that there should have been at least an initial establishment of large numbers of boxelder seedlings right after the 1993 high-flow. However, boxelder is known to exhibit seed dormancy which causes delayed germination. Dormancy can be broken by a 90 day stratification at 5.5° C or a two-week soaking in cold water (Vines 1960, Maeglin and Ohman 1973). Establishment is also enhanced by time delay in seed dispersal, from maturity in the fall until the following spring, ensuring a variety of moisture and temperature conditions is available. However, seed viability is transient (Maeglin and Ohman 1973). We speculate that some sort of regular (at least seasonal) wetting cycle is required for efficient germination; seeds with delayed dormancy and dispersal could then take advantage of moisture availability due to successive high-flows.

The average diametric growth rate of boxelder in Walnut Canyon, based on 4 cores and one trunk cross-section, is 0.37 ± 0.09 cm/yr. Based on results from the few samples (5) which were collected, the size distribution appears to reflect the age distribution. Age estimates of cored trees ranged from 19 years (10.5 cm dbh) to 66 years (26.25 cm dbh). The largest individual surveyed (31.5 cm) is therefore estimated to be 66 to 109 years, but this is admittedly an extrapolation. More cores or cross-sections are required to improve the accuracy of age determination (Figure 19). One core from an unusually slow-growing individual (65 years; dbh =

Table 11. Statistical summary of Walnut Canyon bottom tree survey. Only one individual of Douglas fir, a seedling was encountered in the ten, 240 m^2 plots. Plots were 10 x 12 m and established at random along an approximately one km reach of the Walnut Canyon drainage bottom, centered around the landmark called the Island, below the visitors center.

Species	Mean No. of Stems Per 240 m^2 Plot (n=10)	Percent of Stems Alive (Over all Ten Plots)	Percent of Stems Damaged or Dying	Percent of Stems Dead	Stem Mean X.S. Area at 1.5 m (cm^2)[1]	Total Area 0f Stem (cm^2)	Mean DBH	Mean Diametric Growth (mm/yr)[2]
Boxelder	6.1±3.1[3]	60.6	27.9	11.5	157.1±40.7 (60)[4]	9,426	12.7±1.6	0.37±0.09 (5)
Arizona Walnut	2.2±1.7	77.3	18.2	4.5	49.3±38.2 (15)	738.8	6.4±2.6	0.35±0.06 (9)
Rocky Mountain Juniper	2.1±2.1	52.4	42.8	4.8	244.3±211.8 (17)	4,153.3	13.1±6.2	0.25±0.18[5] (3)
Gambel Oak	22.4[6]±36.6	100.0	0.0	0.0	148.6±201.8 (14)	891.8	9.5±6.0	0.19±0.05 (5)

1 Mean and total stem cross-sectional (X.S.) area was calculated from individuals in size-classes greater than seedling (>1 cm in diameter). All seedlings as defined in this report were less than 1.5 m high; in fact, most were less than 0.5 m high..

2 The number in parentheses represent the number of cores and/or cross-sections which were used.

3 95% confidence interval around the mean.

4 Number of individuals, in size classes greater than seedling, used to calculate means for cross-sectional surface area, total cross-sectional surface area and DBH.

5 95 % confidence limits are given for consistency; because of the small number of samples, they may be unreliable.

6 210 of these individuals were seedlings which had become established since the 1993 flood..

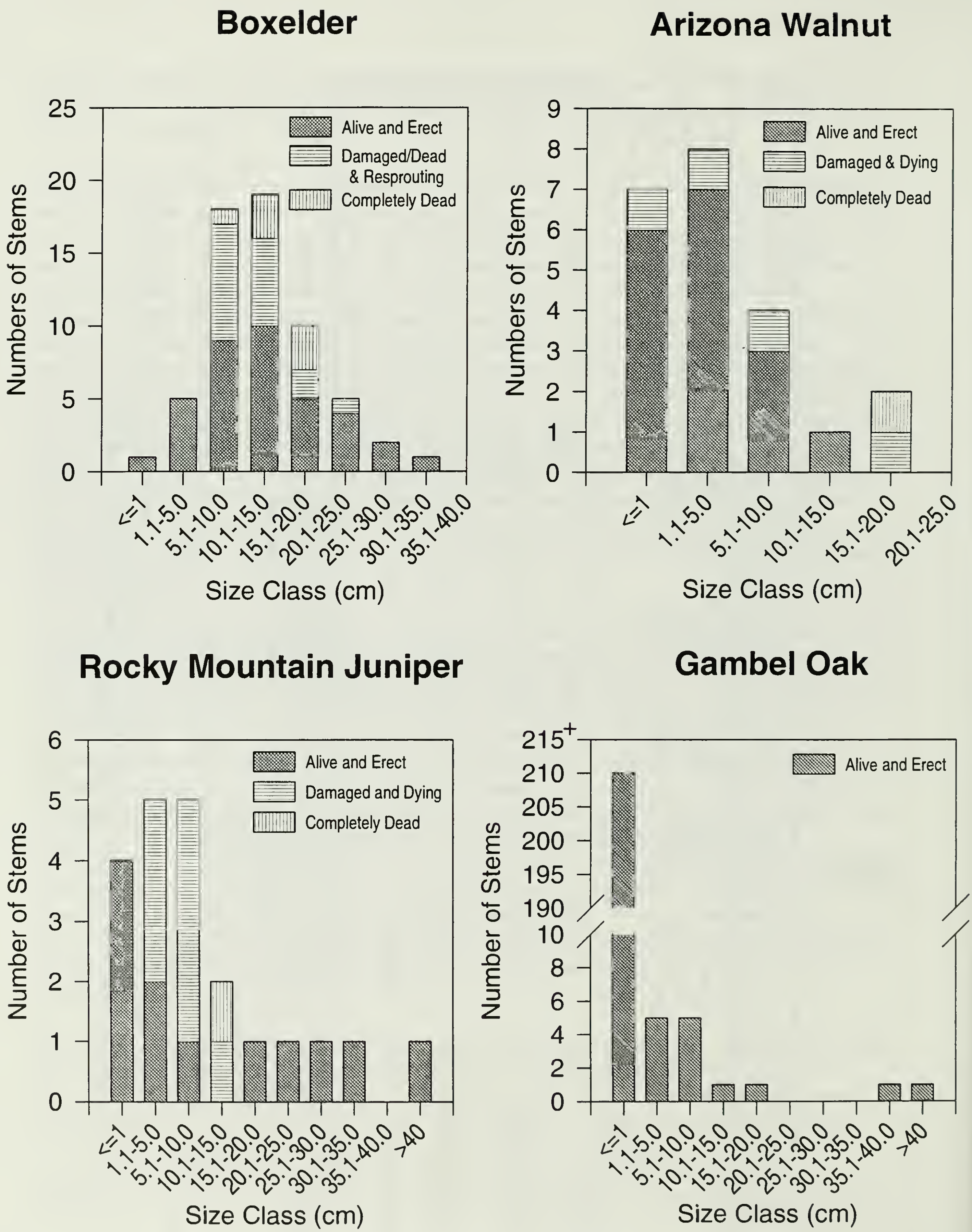

Figure 19. Size class distributions for four tree species growing within the stream channel in the bottom of Walnut Canyon within Walnut Canyon National Monument.

13.5 cm) occurs as an outlier. Seven comparison samples from WFOC seem to indicate a similar size-age relationship (Figure 20). Additional data are required to confirm this.

Maeglin and Ohman (1973) give a range in diametric growth rates from 2.5 cm/yr in excellent conditions on rich alluvial soils to 2.4 mm/yr on prairie soils. Walnut Canyon trees are therefore relatively slow growing indicating a somewhat less than adequate site. Boxelder in comparison canyons exhibited a shrub-like growth form resulting from successive resprouting after damage. Considering the data presented here and information in the literature (Vines 1960, Maeglin and Ohman 1973, Little 1976, Lanner 1984 and Malanson 1993), it appears likely that the best development of this species takes place in bottomland situations subject to regular, but not catastrophic or high velocity, flooding. The deeply incised, Walnut Canyon drainage, is not at all like this. Without the dam, we speculate that the appearance of boxelder in Walnut Canyon would resemble those found in adjacent, undammed and undiverted drainages; i.e., a shrubby resprouter which only rarely attains a tree-like stature. The curtailment of regular flooding has allowed boxelder to regularly develop into a tree in WACA, however the absence of suitable bottomland habitat (i.e., deep, fine alluvial fill) has prevented the development of a true gallery forest. Trees in Walnut Canyon are slow-growing and appear to be reproducing mostly from resprouts.

Arizona Walnut

Arizona walnut trees were encountered in 60% of the plots and ranged in size from seedling to 17.0 cm dbh. Seven seedlings of this species were encountered during the 10 plot survey, about 31.8 % of the total stems encountered. The modal class for alive and erect trees was the 1.1-5.0 cm size class. Only one completely dead tree, in the largest size class, was encountered (Figure18). Three damaged trees were found, one each in the three smallest size classes. Interestingly a large proportion of the trees have survived the 1993 high-flow (Figure 19). Some resprouting was noted in Arizona walnut but only amounted to two stems out of the 22 observed. Evidently, this species reproduces primarily by seed. In terms of total cross-sectional area, it is the third in dominance behind boxelder and Rocky Mountain juniper (Table 11).

The average diametric growth rate of Arizona walnut in Walnut Canyon, based on 8 cores and one trunk cross-section, is 0.35 ± 0.06 cm/yr. Ages of 9 cored or cross-sectioned trees ranged from 22 years (8.0 cm dbh) to 140 years (44.5 cm dbh)[21].

The size-frequency plot for Arizona walnut indicates that this species may be invading the bottom of Walnut Canyon. Most individuals are in the smaller size classes with few, large individuals. This particular pattern is probably preserved through time. Individuals may establish and grow for a period of time, only to be eliminated by one or more subsequent releases from the Lake Mary's. After which, surviving larger trees contribute to replenishment of the seed bank and a new crop of seedlings. The invasion, in other words, appears to be a perpetual one.

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[21] This particular individual, one of the largest we observed in Walnut Canyon was not situated in any of our plots but was sought out in order to provide as long a dendrochronological sequence as possible.

Rocky Mountain Juniper

Rocky Mountain juniper is a slow-growing upland species which varies in form from a large shrub to a small or medium sized tree (Vines 1960, Little 1976). Like Arizona walnut, it appears to be perpetually invading the bottom of Walnut Canyon. Juniper trees were encountered in 50% of the plots and ranged in size from seedling to 44.0 cm dbh. Four seedlings of this species were encountered during the 10 plot survey, about 19 % of the total stems encountered. The modal class for alive and erect trees was the seedling size class. Only one completely dead tree, in the 10.1-15.0 cm size class, was encountered (Figure 18) However, a relatively large number of damaged and dying trees were encountered in the three smallest size classes above seedling, approximately 38.1 % of the total stems. All of these individuals were partially to almost completely uprooted and chlorotic and will almost certainly die. Only one stem showed evidence of vegetative reproduction. This species, like Arizona walnut reproduces primarily by seed. In terms of total cross-sectional area, it is the subdominant tree in this reach of the canyon bottom behind boxelder.

The average diametric growth rate of Rocky Mountain juniper in Walnut Canyon, based on 3 trunk cross-sections, is 0.25 ± 0.18 cm/yr (Table 11). Ages of sampled trees ranged from 17 years (6.5 cm dbh) to 27 years (7.5 cm dbh) The size-frequency plot for Rocky Mountain juniper (Figure 19) indicates that this species, like Arizona walnut may be perpetually invading the bottom of Walnut Canyon. Again, most individuals are in the smaller size classes with few, large individuals. All seedlings were less than one year old and had become established after the 1993 high-flow. Most of the flood damage appears to have been inflicted on individuals between 1.1 and 15.0 cm dbh. Unlike Arizona walnut only a few small trees (i.e., ≤15 cm dbh) appear to have survived the 1993 high-flow. Larger trees were observed to occupy those canyon bottom sites which were outside the main channel proper or on raised gravel bars somewhat protected from flood ravages by their position and size. Rocky Mountain juniper will always maintain at least an evanescent presence in the canyon bottom as long as the drainage remains dammed. The tree is not at all important in the bottoms of the adjacent canyons visited being generally less than 1% of the plant species composition.

Gambel Oak

Gambel oak is another upland species which grows in the form of a large shrub or a small to medium sized tree depending upon environmental conditions (Vines 1960, Little 1976). Gambel oak was encountered in only three out of the ten of the plots and ranged in size from seedling to 41.0 cm dbh. The modal class for alive and erect trees was the seedling size class (Figure 19). Although the frequency of this species was low, a large number of stems in the seedling class; about 94% of the total stems, were encountered. In this survey, these were almost always around a "parent" tree or trees on the periphery of the channel. Gambel oaks possess both lignotubers and rhizomes (Lanner 1984). A few of these "seedlings" were excavated and appeared to have rhizomatous connections. Many, if not most, of these seedling-sized stems are ramets, the products of vegetative reproduction. All of these "seedlings" were less than 0.25 m high and were probably induced due to the effects of the 1993 high-flow as damage to the tree's crown can remove the hormonal suppression of dormant buds on the rhizomes or lignotuber. Nevertheless,

none of the larger individuals encountered showed any overt signs of flood damage except for trapped debris in the crotches of limbs. Perhaps the stresses caused by inundation may also induce ramet production in Gambel oak.

The size-frequency plot for Gambel oak (Figure 19) indicates, once again, a pattern of perpetual invasion. Larger trees, including their ramets, perhaps as much as 88% of the seedling-sized stems sampled), tended to occupy protected microsites in the canyon bottom outside the main channel proper or on raised gravel bars. The remaining seedling sized individuals, true seedlings, had become established in the channel proper after the 1993 high-flow but will undoubtedly be removed by the next major release from the Lake Mary Reservoirs.

The average diametric growth rate of Gambel oak in Walnut Canyon, based on 5 cores, is 0.19 ±0.05 cm/yr, making it the slowest-growing tree of the four common ones. Ages of sampled trees ranged from 53 years (14.0 cm dbh) to 166 years (30.3 cm dbh). In terms of total cross-sectional area, it is the least important of the canyon bottom trees in the surveyed reach of Walnut Canyon.

Growth Response of New Mexico Locust to the 1993 High-flow

New Mexico locust was not among those species sampled in the canyon bottom tree survey because its growth form is more that of a shrub than a tree. However two of the larger stem cross-sections were collected and their annual rings investigated. For their size, the plants sampled were rather old. Stems 5.0 and 7.2 cm dbh were 20 and 36 years old, respectively; an average diametric growth rate of 0.23 cm per year. The larger of these individuals was already dead due to 1993 flood damage. However the other sample was from a live plant which not only survived the high-flow, but exhibited a pronounced and positive growth response (Figure 21). Prior to 1993, growth ring widths averaged 1.02 ± 0.23 mm per year. The 4.5 mm width for the 1993 growth season, after the high-flow, represents a four fold increase. Previous spikes in the growth history as presented in Figure 21. may be related to previous, documented high-flow events in 1983 (lagged one year?) and in 1979 and 1980. A spike around 1977 may represent a response to a rare summer flow. We have described previously that overall New Mexico locust was not severely affected by the 1993 high-flow. Very likely, older, senile plants are killed and removed by the irregular flooding whereas younger, more vigorous stems can withstand the onslaught and even benefit by it.

Vegetation of the Sinagua Indian Ecosystem

There is little available evidence to reconstruct the historic scene and ecosystem inhabited by the Sinagua Indians at WACA (Bruce Anderson, personal communication, 1994). The vegetation in the desert Southwest has changed very little over the last 3,000 years (mid-Holocene) and where change has occurred, the trend has almost always been towards increasingly arid vegetation (Betancourt et al. 1990, Hastings and Turner 1965). A fire history and stand structure analysis of the pinyon-juniper woodland at WACA (Despain and Mosley 1990) states that, "Assuming the woodland was much more open when the area was inhabited by the Sinagua Indians (if not practically denuded by the significant population estimated to have lived there), woodland stands

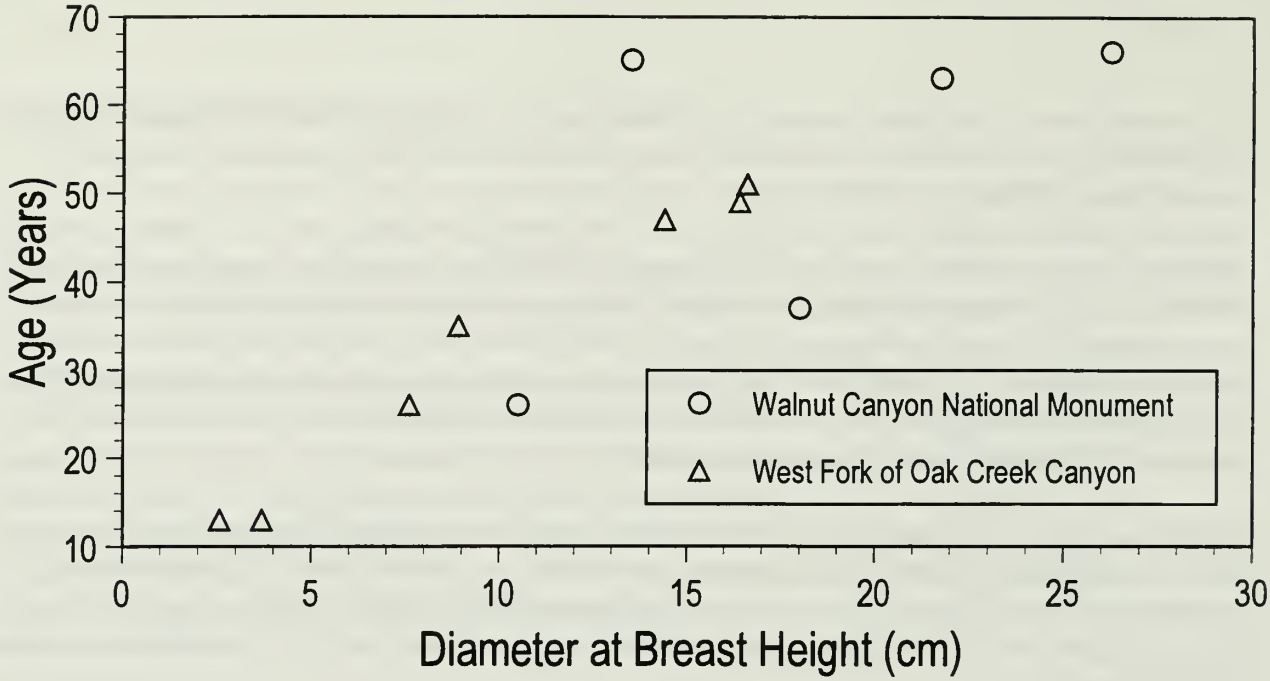

Figure 20. Size-age relationship for five boxelder specimens collected from the bottom of Walnut Canyon and seven specimens from the West Fork of Oak Creek Canyon.

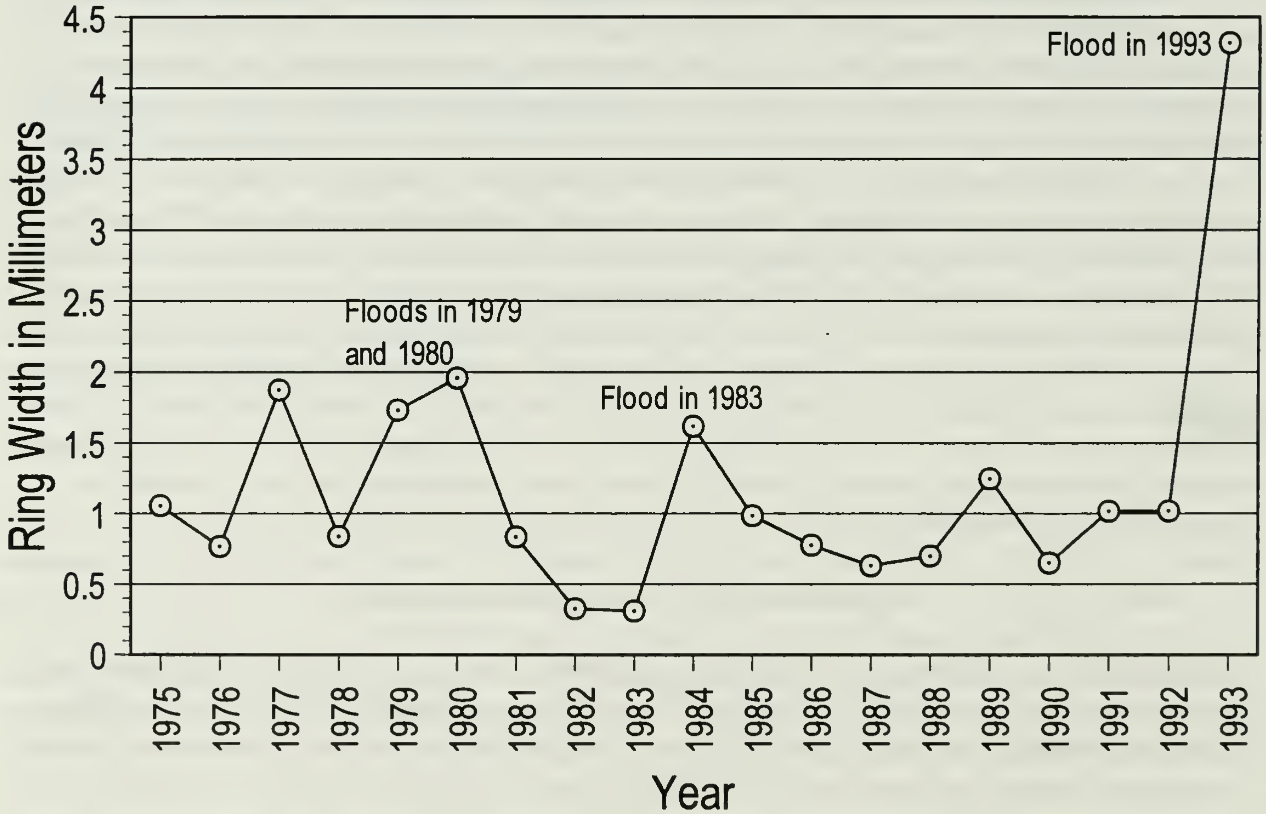

Figure 21. Changes in ring widths through time as revealed in a cross-section of a New Mexico locust growing in the stream channel at the bottom of Walnut Canyon. Responses to previous floods may also be indicated.

in the area may have never been in a condition similar to today's. Although present stands may be "natural" under current conditions, these woodlands do not appear to represent historical conditions." A study of midden pollen done at Chaco Canyon National Monument (Betancourt et al. 1990) documents the decrease in upland tree species between 1.2 and 0.5 thousand years ago. The authors postulate that the woodland depletion is due to the fuel needs of the Anasazi, not a climatic shift where the vegetation shifted from a woodland to desertscrub. A climatic caused shift in the vegetation is not plausible as this is the only time loss of upland tree pollen occurred in over 8,000 years at Chaco Canyon. Also, it has no parallel elsewhere in the Southwest. Samuels and Betancourt (1982) showed by computer simulation that fuel needs by Native Americans over a 200 year period could account for loss of 13,000 ha of woodland, assuming a maximum density of 15 cords/ha.

No information or studies were located documenting any vegetation or floristics associated with past true riparian communities of prehistoric Walnut Canyon. Unfortunately, usable ancient rat middens are probably very rare in the canyon bottom due to their removal by past and present periodic flooding. However, some prehistoric woodrat nests might be found within 30 meters of the bottom, close enough to be within the foraging range of woodrats, but high enough above the canyon to be protected from flooding. Such a search however was beyond the scope of this study.

CONCLUSIONS

Hydrology

Walnut Canyon was historically an ephemeral drainage as evidenced by historic photographs, literature, and anecdotal reports. Flow historically occurred seasonally during snowmelt runoff in early spring and monsoonal thunderstorms in July-September. Ephemeral flow conditions are supported by the presence of 300 year old ponderosa pine and Douglas fir trees on rocky terraces in the bottom of the Walnut Canyon. Historical flows were not sufficient or frequent enough to remove the trees. Today, these terraces are evidently a relatively stable component of the canyon bottom landscape element in the Walnut Canyon drainage.

Inflow, lake level and spill data are lacking or sporadic. Long-term data (lake level, gross lake volume, and surface water diversion) exist only for Upper Lake Mary. Local streamflow gage data is limited to crest-stage information on Fay Canyon. Nearby gages, such as the USGS Little Colorado River station, exhibit different streamflow characteristics and should not be used to estimate flows in Walnut Canyon.

Reservoir construction and storage has altered the frequency of flows in Walnut Canyon and has probably altered the magnitude and duration of the flood peaks. A simple mass balance model indicates that since 1950, flow events through Walnut Canyon have been reduced from almost an annual event to one in every nine years, due to the construction of Upper and Lower Lake Mary. The duration of spills into Walnut Canyon varied from three weeks in 1973 to ten weeks in 1980. Annual runoff into Walnut Canyon has been reduced from about 290,000 ac-ft to about 25,000 ac-ft due to the presence of a single reservoir. Annual runoff has probably been reduced another

order of magnitude or more by the construction of both reservoirs. Additional reservoir storage to support increasing growth of Flagstaff would extend the "fill and spill" cycle and further reduce the frequency and duration of flows into Walnut Canyon.

The timing of spring runoff and/or high flows has also been altered by reservoirs and surface diversion to the City of Flagstaff. Anecdotal and photographic evidence indicates that summer flows have been completely eliminated, other than local runoff events, through Walnut Canyon. Since the construction of the reservoirs, most flows through Walnut Canyon have occurred in years with above normal snowpacks or during wet periods in which the reservoirs were full or as a result of heavy precipitation.

The impacts of geologic fracturing and faulting on channel transmission and storage in Walnut Canyon cannot be quantified but are suspected to be large. Water losses from the reservoirs are well documented and are in fact one of the reasons for constructing Upper Lake Mary. Discharge of natural seeps in Walnut Canyon may be enhanced by upstream reservoir storage and promote the maintenance of obligate riparian plant species, such as willows within "rufugiae" in WACA. Reservoir storage may also help recharge the Coconino aquifer, the source of water for the Flagstaff well field.

Comparative studies of nearby tributaries such as Fry Canyon and the West Fork of Oak Creek Canyon indicate that these naturally functioning channels (i.e., no diversions, reservoirs or revetments) receive annual and seasonal runoff absent from Walnut Canyon. The annual runoff events in these drainages seem to maintain channels which are more open (less encroachment of riparian vegetation) and which contain more pools and large substrate. It is believed that these conditions promote the maintenance of naturally occurring vegetation including obligate riparian plant species.

In answer to our working hypothesis, we must reject the assumption that the imposition of the two upstream reservoirs has had no effect on the hydrology of Walnut Canyon in WACA.

Dendrochronology

Only two species, ponderosa pine and Arizona walnut, yielded usable chronologies. Although some interesting information was gleaned from dendrochronological analysis, no evidence relating any effects of dam-induced dewatering on growth of either of these trees growing in the WACA canyon bottom was observed. There was no substantive change in the mean tree-ring index of ponderosa pine in and directly adjacent to the canyon bottom over three discrete time periods: prior to the construction of Lower Lake Mary Dam; after Lower Lake Mary Dam's construction, prior to the building of Upper Lake Mary Dam; and after both dams were in place. In fact growth rates, as represented by the mean ring index actually rose somewhat between 1942 and 1992 after the construction of Upper Lake Mary Dam.

Ponderosa pine trees in and adjacent to the old stream bed are in a complacent site and "buffered" somewhat from climatic variation. The mean tree-ring index was relatively stationary over the three critical time periods. Canyon bottom and rim/slope mean ring indices were substantively

different only during the period between 1904 and 1941, a period of relatively high, though subsequently declining annual precipitation. The most probable explanation for this pattern is that rim/slope trees, fully exposed to sunlight and a longer effective growing season than the shaded individuals in a canyon bottom where snow may accumulate and remain longer, are capable of a more intense growth response, or a release from drought at the beginning of the century, during the more relatively moist period between 1905 and 1923.

Arizona walnut ring index means showed similar, but more pronounced variation, to the point of being nonstationary, when calculated over these same time periods. The mean ring index declined after 1904 and before 1941, but then rose again to pre-1904 levels when calculated between 1942 and 1992. Arizona walnut is a facultative riparian species. Indeed, at least one sapling has become established near a primitive trail about 50 m above the canyon bottom. The depression in the mean ring index of Arizona walnut over the 1905-1941 period, the time span between the dam construction, is more difficult to explain. A possible explanation is that, during this relatively moister period, though there are droughts on either side, snow accumulation in the canyon bottom may have been relatively greater. Arizona walnut, a deciduous tree, may have been more susceptible to growth rate depressions caused by a relatively shorter effective growing season than canyon bottom ponderosa pines.

If the placement of the two dams had any effect on growth of canyon bottom trees surely it should have been manifested in a permanent depression of growth rates after the dams were constructed. In any case, any effects of the interposition of the two Lake Mary Dams in the Walnut Canyon watershed on growth rates of canyon bottom ponderosa pine and Arizona walnut may be manifested more in the germination, establishment, and early growth of trees and not in the growth dynamics of established, mature trees.

The use of dendrochronology to reveal flood or high-flow events based upon damage or reaction wood changes documented in the tree-ring record was not possible in this study. No scars were indicated by any of the cores taken form canyon bottom inhabiting trees. However, lack of appropriate replication as well as improper extraction of cores for reaction wood/scarring analysis prevent a conclusive finding. Preliminary studies (Malanson 1993) have indicated that rings may not be useful indicators of flood events because of individualistic responses and the contradictory effects of release from competition as other trees are toppled during erosion events. Malanson (1993) gives a good review of "dendrohydrological" studies and concludes that "dendrochronology can help reconstruct the spatial distribution of past responses to environment and may be able to be used in the generation of a model of landscape reduction, or tree-rings may be used to test hypotheses ***if the relations which they represent are clear***".[22] In other words, tree-ring growth is sensitive to a variety of factors, especially competition from neighboring trees and trends in climatological factors. In order for dendrochronology information to be useful, these confounding effects must be distinguished from effects due to instream flows. Future dendrohydrological studies of WACA canyon bottom trees should take this into account, along with the lack of discharge data with which tree growth responses could be compared.

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22 Emphasis added.

Vegetation

Historic photographs suggest that there has been an increase in vegetation since the 1940's, the date of Upper Lake Mary Dam (Brian 1992). There are no reliable data prior to this time period which documents the status of the canyon bottom vegetation. We suspect that before Lower Lake Mary Dam was in place (1904), seasonal flow was sufficient to maintain a stream bed largely clear of vegetation. Quantitative documentation of canyon bottom vegetation is not available until 1973 when the first study was done.

Vegetation Dynamics of the Walnut Canyon Bottom

The canyon bottom vegetation within the boundaries of WACA has reached a dynamic equilibrium under the post-1941, Upper Lake Mary flow regime. A conceptual model relating vegetation dynamics in the bottom of Walnut Canyon to precipitation amounts and patterns, Lake Mary overflows and substrate is presented in Figure 22. The vegetation types which occupy the dry Walnut Canyon bottom constitute "transitional" vegetation. It is maintained as a result of the irregular and unpredictable high-flow events resulting from winter/spring overflows of Upper and Lower Lake Mary. Such events are relatively rare in the summer and early fall when flows may result from local runoff due to localized monsoonal storms or tropical disturbances.

This low rate of disturbance is enough to remove non-flood and nondisturbance adapted vegetation from the bottom of Walnut Canyon. However, the canyon remains essentially dry most of the time. Major winter and spring flows may be absent for as long as a decade and summer flows an indeterminate length of time. What open water exists is largely the result of snow melt and monsoonal precipitation, which temporarily fills pools and tinajas. However, throughout most of the canyon bottom, such long periods of imposed "drought" effectively eliminates obligate riparian species, such as species of willow, which are now restricted in the canyon bottom to the vicinity of seeps.

We have established that even a relatively severe, statistical high-flow event of-and-by itself, such as occurred in the winter and spring of 1993, does not totally remove all the vegetation which has invaded the canyon bottom. Disturbance adapted species such as New Mexico Locust, red osier dogwood, boxelder and Arizona rose were observed to be resprouting vigorously. The vegetation is generally dormant at the time of year when these high-flows are most likely to occur and the extremely cold runoff would tend to reduce plants' metabolic activity, thereby enabling roots to survive a relatively long period of inundation.

High-flow events will remove senescent trees, many mature trees, which lie in the path of the flood, and most newly established tree seedlings or saplings of upland invaders such as Gambel oak and Rocky Mountain juniper. Canyon bottom tree species, which have survived through the germination, seedling, and pole stages, will remain. Rocky Mountain juniper and other species with a low flood tolerance will be periodically removed or damaged by subsequent high-flows. Boxelder appears to be reproducing primarily through vegetative propagation and seedling establishment is sparse. The size-distribution could indicate gradual removal of this tree from the drainage over time or perhaps boxelder can persist indefinitely with a low level of

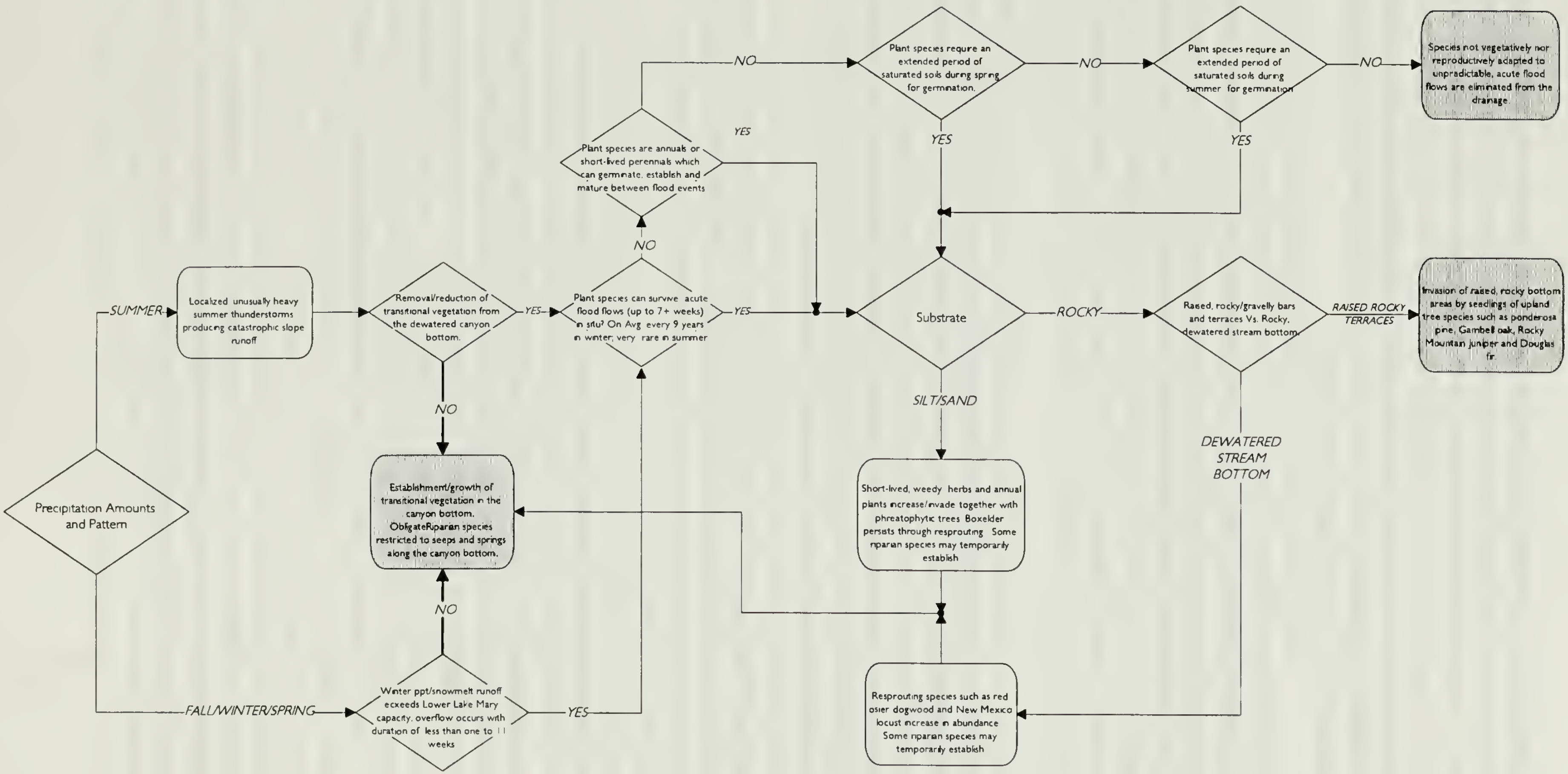

Figure 22. Conceptual model identifying the relationships between precipitation pattern and amounts, Lake Mary overflow and vegetation dynamics in the bottom of Walnut Creek,Walnut Canyon National Monument, Arizona.

recruitment via sexual reproduction. Additional research is needed to make a more well informed determination. Narrowleaf cottonwoods have short-lived seeds which require full sunlight and a saturated soil for an extended period of time in order to germinate (Vines 1960, Lanner 1984). Because of the now irregular and rare high-flows, these may be in the process of removal from the system. However, once established, phreatophytes such as narrowleaf cottonwood, can tap seeps and groundwater sources below the stream bed and persist through an extended period of time in the absence of flooding.

The slight increase from 1989 to 1993 of New Mexico locust, especially after the runoff event of 1993, attests to the hardiness of this leguminous shrub or small tree species. In fact, the growth rate of one specimen, as revealed by the rings in a cross-section, increased by a factor of almost four times the previous average. The fast growth rate, accompanied by the tendency of this species to root sprout is an adaptation to disturbances such as irregular flooding and renders it useful for erosion control (Johnson 1993). The hardiness of the species increases the likelihood that New Mexico locust will continue to form thickets and colonize the canyon bottom at WACA.
Bare, sandy areas are invaded by weedy herbs and forbs, many of them introduced species; an "annual disclimax". The most dramatic example is the area behind Santa Fe Dam, but smaller patches of sand/silt filled areas are interspersed throughout the drainage. Undoubtedly, these are scour holes during a high-flow event. In theses areas, the typical course of events appears to be an invasion by weedy herbs, ephemeral plants, and short-lived perennials. Primary among them are mullein, motherwort, various species of bunch grass, species of brome grass, dogbane; a vigorously resprouting herbaceous perennial; and dragon sage.

Plant species which are neither adapted to disturbance-creating high-flow events by resprouting, rapid germination and establishment, annual life-forms, nor to surviving a long drought through tapping ground-water sources, will eventually be eliminated from the bottom of the drainage system.

In summary, the vegetation (Figure 23) we see occupying the various substrates (Figure 24) in the bottom of Walnut Canyon is a cyclical, transitional vegetation surviving and maintaining itself because of the perpetual disturbance. Campbell and Green (1968) have described such a "perpetual succession" in the Sycamore Creek drainage in eastern Maricopa County. However, unlike this site and other local, undammed drainages studied in this report, disturbance creating flows are not seasonal in WACA, they occur every 9 years. As a result, the WACA canyon bottom is more "upland-like" with a much denser cover of vegetation in comparison to these other sites. Also, the relatively rare, sediment-laden, major flows though WACA have created a large number of silted in areas which support an "annual disclimax" absent from comparison canyons.

The Walnut Canyon channel vegetation is composed of several components which are constantly being renewed by the intermittent cycles of unpredictable high-flow events followed by periods of dewatering of unpredictable duration. The four major assemblages based on their geomorphic preferences are:

- **A Rocky , Upland Terrace Assemblage** consisting of upland tree and shrub species, such as ponderosa pine, Douglas fir, Gambel oak, squaw bush, snowberry, etc., which have invaded rocky terraces and which are protected from all but the most severe flooding.

- **A Rocky, Dewatered Streambed Assemblage** dominated by vigorous resprouting species such as, Arizona rose and New Mexico Locust, and also some invading upland tree species.

- **A Rocky, Dewatered Bar Assemblage** dominated by red osier dogwood.

- **A Sand-Silt Dune and Scour hole Assemblage** consisting of phreatophytic trees along the periphery and short lived weedy perennials and herbaceous plants toward the center of the drainage bottom. This assemblage includes Phillips' (1990) annual "disclimax" vegetation associated with the silt fill behind Santa Fe Dam as well as silted-in scour holes within the upper part of the drainage.

Comparison Canyons

A comparison of nearby tributaries that are undammed shows that Walnut Canyon, if it did have permanent or seasonal flow every year, would be able to support a more typical riparian ecosystem. Based on observations made in comparison canyons, an undammed Walnut Canyon channel should be relatively free of vegetation in most cases, and in the worst cases, vegetation could probably be bypassed without leaving the channel proper. New Mexico Locust and other thicket formers (red osier dogwood, Arizona rose, etc.) should be largely restricted to adjacent banks and slopes away from the channel proper. We feel that the presence and importance of willows should be substantively higher in Walnut Canyon based on their abundance in adjacent, undammed drainages. We also feel that boxelder should not be as prevalent an overstory component in an unaltered Walnut Canyon and that its primary contribution to the vegetation would be in the shrub layer. The situation in Walnut Canyon maybe somewhat analogous to that described by Campbell and Green (1968) in the Sycamore Creek watershed. In the upper part of this drainage, the channels are V-shaped and incised and subject to destructive high-flows. "Presumably, because of these factors, dbh and height of trees recorded on quadrats in the upper 21 mile sector decreased with elevation (Campbell and Green 1968)". This supports the contention that sizes of boxelder trees are generally greater in Walnut Canyon than comparison canyons due to the influence of the two Lake Mary dams in lowering the frequency of "destructive high-flows."

Age-Size Distribution of Canyon Bottom Trees

Based on their size-distributions, three of the four important tree species occupying the bottom of Walnut Canyon , Arizona walnut, Rocky Mountain juniper and Gambel oak, are perpetually invading the stream channel. The largest size class of live stems is the "seedling class"; in the case of Gambel oak, the latter includes ramets. The often long period of time between high-flow events allows seedlings of these species to germinate and become established afterwards. Large numbers of these are then eliminated by the next major flow and if a few survive, as for example, appears to be the case for Rocky Mountain juniper, they are eliminated by the next disturbance

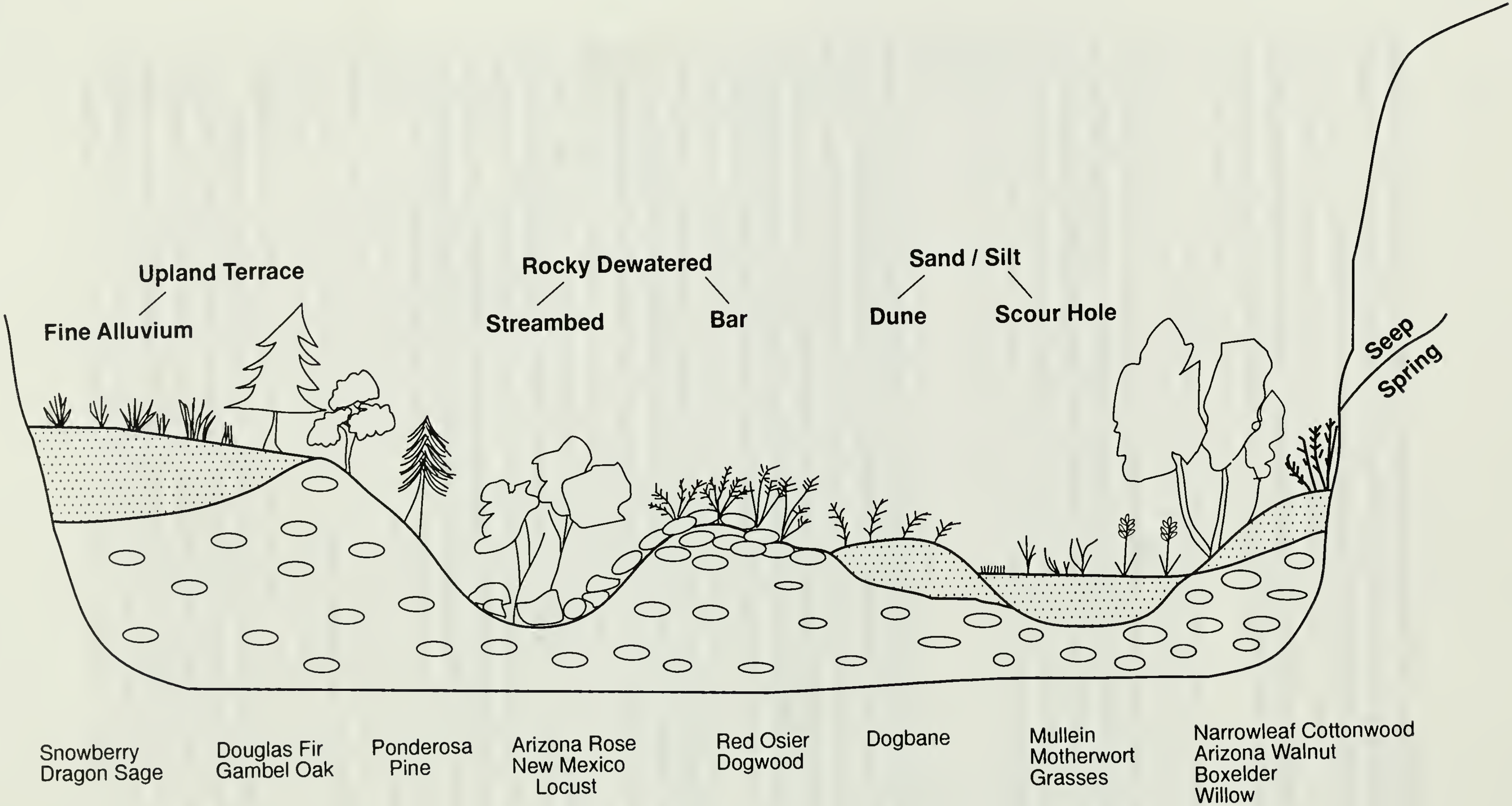

Figure 23. Diagrammatic illustration of the canyon bottom vegetation and substrate selection at Walnut Canyon National Monument.

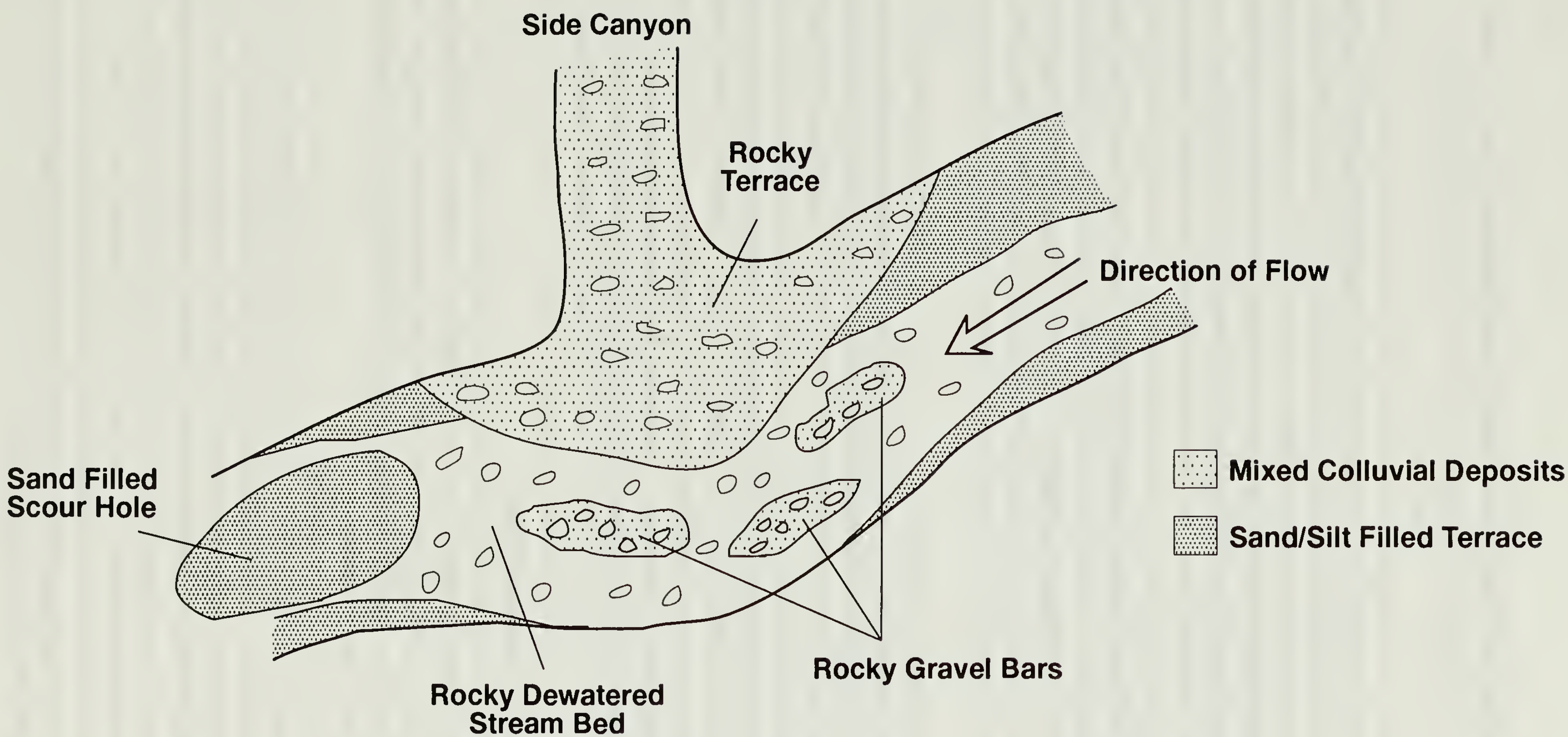

Figure 24. Diagrammatic illustration (map view) of the canyon bottom substrate at Walnut Canyon National Monument.

and so forth. By observation, larger, more mature trees of these species tend to occur on the periphery of the channel or on raised gravel bars protected from all but the largest flows.

Boxelder, the most important tree occupying the canyon bottom is maintaining itself by means of vegetative reproduction; only one seedling was encountered in 10 plots totaling 0.24 ha. Precise age determinations are extremely difficult in this species because heartwood is almost always soft or rotten; cores are incomplete or break upon removal. Nevertheless there appears to be a direct and positive correspondence between age and size. Its "bell-shaped" size distribution, together with the lack of seedling-sized individuals could indicate that it is slowly being eliminated from the system. On the other hand, germination and establishment of boxelder could require more than just an opportune high-flow; some combination of events, for example a summer high-flow coupled with a succeeding winter high-flow, or vice-versa might be necessary to produce a good crop of seedlings. Such a pulsed establishment is not reflected in the data. It is possible that such a vigorous resprouter can maintain itself with low rates of seedling establishment as long as some sexual recruitment occurs on a regular basis over a long time period.

In answer to our working hypothesis, there appears to be a causal relationship between the damming of Walnut Canyon and the past and present canyon bottom vegetation dynamics at Walnut Canyon. Past and present plant collections have shown that hydrophilic plants, such as marsh smartweed, no longer grow at WACA. There is scant historic data, such as written descriptions or photographs prior to 1904. However, Brian (1992) documents a general increase in vegetative cover in the canyon bottom and north-facing slopes in the past 30 to 40 years. Our field work has shown that little overall change has occurred on eight, permanent, canyon bottom monitoring sites over the last four years. Indeed, vegetation cover today appears to be similar to that found in a study twenty years ago. However, the system is dynamic and temporary, quantitative changes in species composition have undoubtedly occurred between high-flow events.

The Prehistoric (Sinaguan) Vegetational Scene

We will probably never know precisely the historic scene and plant communities inhabited by the Sinagua Indians 600 years ago. Although the reason the Indians abandoned the area prior to the 1400's is debated by anthropologists, drought and the subsequent dewatering of the canyon, due to natural climatic change, may have contributed.

Ancient Native Americans had a profound effect on the landscapes they inhabited and it is likely that the Sinagua were no exception. They may have introduced yuccas and most likely depleted the pinyon woodland for fuel and timber requirements. Except for vegetation changes brought about by Sinaguan exploitation, the plant communities in pre- and post-settlement times probably bore a great deal of similarity to those found in the vicinity of WACA today. Existing macrofossils contained in woodrat middens indicate that WACA vegetation has changed very little in the past 3,500 years. Unfortunately no macrofossil deposits from the canyon bottom of WACA have been analyzed. At the present time, little can be said about the nature of the canyon bottom plant community as the Sinaguan Indians knew it.

RECOMMENDATIONS FOR FURTHER RESEARCH

Hydrology

Hydrological Data Collection

The National Park Service and the City of Flagstaff should begin collecting hydrologic information to monitor and document the extent of runoff events and impacts of flow on Walnut Canyon vegetation. We recommend that the city of Flagstaff implement the following actions and protocols to improve knowledge about reservoir management and releases into Walnut Canyon:

- Install either a continuous or crest-stage gage blow Lower Lake Mary to record releases into Walnut Canyon;
- utilize new and inexpensive electronic datalogger equipment to continuously monitor Upper and Lower Lake Mary lake levels on a daily basis;
- rate each spillway and install a staff plate to allow for estimates of spills during overflow events.

We recommend that Walnut Canyon National Monument implement a program to record (quantitatively and visually) flows through Walnut Canyon. This program could include the installation of a staff plate at an accessible location and a crest-stage gage to estimate peak flows.

Hydrological and Ecological Significance of Seeps and Groundwater

Water seeping into the canyon bottom through fault lines traversing the canyon walls provides moisture for mesic dependent herbs and shrubs, as well as for invertebrates, birds, and mammals. We observed that willow species (*Salix laevigata* and *S. bonplandiana)* and narrowleaf cottonwood were adjacent to seeps and were probably dependent upon them for survival especially during times of drought. Questions which could be asked include:

- Are Walnut Canyon seeps affected by reservoir state/releases and well pumpiing from the reservoirs and Lake Mary well field?
- Are seep flows affected by annual climatic variations?
- Is there substantial interstitial flow in the Walnut Canyon bottom gravels?

Vegetation

Age-Size Class Distribution and Reproductive Ecology of Boxelder and Narrowleaf Cottonwood

A limited study of the size - frequency distribution of ten randomly placed 240 m^2 plots with several important canyon-bottom trees was done in support of the present study. We feel that an expanded study is justified in order to answer several important questions:

- What is the present ecological status of boxelder in Walnut Canyon? Data presented above suggest that sexual reproduction may be limited; reproduction through resprouting seems to be the norm. Gradual extirpation of this species from Walnut Canyon may be taking place.

- Furthermore, boxelders appear to attain a greater size in Walnut Canyon than in adjacent drainages. It is suggested that this difference in growth form may also be related to the dam-produced changes in the flow regime. Do these growth changes correlate with documented changes in flow?

- What is the present ecological status of narrowleaf cottonwood in Walnut Canyon? Even though Phillips' (1990) study considered that narrowleaf cottonwoods were an important canyon bottom species in WACA, no individuals of this species were sampled within the ten large, random macoplots described above. We feel that narrowleaf cottonwood is a rarer species than Phillips (1990) reports. Furthermore, a personal communication from Dr. Margaret Moore of the NAU School of Forestry, revealed that narrowleaf cottonwood is a declining species locally due to both damming of drainages and water diversions.

- Is there any evidence that past flooding has lead to a "pulse" of establishment for boxelder or narrowleaf cottonwood?

An intensive survey of canyon bottom trees (50 - 100 ± permanent, randomly located macroplots, 200-300 m^2 in extent) coupled with increment core and stem cross-section analyses will be a successful way to answer the above questions.

Monitoring Design Improvements

We found some problems with the RASES method used by Phillips (1990) to study the permanent, canyon bottom ("riparian") vegetation monitoring plots. The following is a brief discussion of problems encountered and our recommendations:

- Tree measurements were divided into three size classes (seedlings and saplings, poles (or advanced regeneration), and mature trees). The size classes for these (<5 inch (in), 5-9 in, >9 in) did not adequately describe the trees encountered in the plots we resurveyed (especially for Gambel Oak, narrowleaf cottonwood, juniper, walnut, and boxelder). We suggest that all trees be measured at breast height and that such arbitrary size classes be eliminated.

- Both shrubs and herbs were surveyed in a Daubenmire plot (20 X 50 cm). The Daubenmire method (1968) is only suitable for herbs and grasses (Mueller-Dombois and Ellenberg 1974). Shrubs are better surveyed in larger plots, depending upon the species encountered (1 X 1 m, or larger).

- An underlying assumption for this method is that the 0.1 acre plot is presumed to be homogeneous and that the plot does not border an ecotone (i.e., border two plant communities). The canyon bottom at WACA is a very heterogeneous habitat. It has large open sandy areas in some areas and rocky patches with thickets and closed canopy woodland

in others. The plots are often dominated by one species in one half while the remainder is covered by two to three other species. The dry stream bed is bordered by alluvial terraces, cliffs, and rocky boulders. For example, the terraces bordering the channel are often covered by snowberry or desert olive, while sandy areas are often covered by red osier dogwood. We suggest that in future resurveys that the RASES method not be used. Instead, data from several line intercepts placed perpendicular to the stream flow (from one side of the canyon wall to the other) could be used to collect tree, shrub, and understory measurements. Notes should be taken to indicate the change from one vegetation and substrate type to the next. With the appropriate constraints taken into acount, i.e., plot size and shape, Braun-Blanquet relevés could also be used.

- The Daubenmire method used by the RASES method calls for a record to be made of each species by visually estimating coverage into one of seven cover classes; then the canopy cover percentage midpoint is used in computations. This was not done by Phillips (1990) nor by our resurvey. Again, with line intercept data, no estimates are necessary, but rather the actual intercepted cover is recorded.

- The 50 Daubenmire plots were arranged along the two or three parallel running strip lines by Phillips (1990), thus sampling the center of the 0.1 acre plot. We found that the plot was better sampled by placing five of the plots radiating away from each corner (for a total of 40), plus ten plots placed in the middle of the 0.1 acre plot, for a sum total of 50.

- The final tally of relative cover, density, and frequency recorded by Phillips (1990) incorporated the tree data from the three subplots with the shrub and herb data collected from the Daubenmire plots. As mentioned in the first item, it does not make sense to combine data from the 0.1m plots as the vegetation for the entire plot is not homogeneous.

- We suggest that the permanent, vegetation monitoring plots established by Phillips (1990) be marked on all four corners with rebar and attached metal tags noting the cardinal direction. We had a difficult time relocating the plots even with the assistance of the original researcher, photographs, and notes. No difficulty was encountered relocating the Jenkins et al. (1991) WC2 plot. We have prepared sketch maps of the monitoring plots resurveyed by this study. These maps are on file with our original data sheets and notes for future investigators. It is very probable that a Global Positioning System (GPS) referencing of the sites is not possible due to the depth of the canyon and the steep walls.

Synthesize Existing Data on Vegetation

Numerous vegetation studies for the canyon bottom, slope, and rim areas exist for WACA. We suggest that a synthesis of this information be undertaken and a report written to evaluate and interpret the data.

Dendrohydrological Study

It is possible that a dendrohydrological research project could be designed and implemented, to attempt to accurately determine the pre-settlement (before 1850) high-flow frequency in Walnut Canyon. If so, we recommend a small pilot study be done to ascertain whether a larger scale project is feasible. A large number of cores (several per individual tree) would be required together with intensive searches for and analysis of flood scars. The final number of cores collected could number in the hundreds. Since there is no discharge data available to correlate annual tree rings with flooding, the cost-benefit may be constraining.

Questions asked include:

- Is there any historic evidence of high-flow induced scarring in the tree ring record?
- Have any recent, documented high-flows (since 1950) left recognizable scars?
- Is it feasible or possible to estimate pre-dam high-flow frequencies (pre 1904 as well as pre 1940) based on a flood scarring record in the tree rings.
- Have high-flows coincided with "pulses" of canyon bottom tree establishment (see also age-size class distribution study recommendation above)?

This study could be done separately or in conjunction with the age-size class distribution and reproductive ecology of boxelder and narrowleaf cottonwood described above.

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CITED LITERATURE

Aitchison, S.W. 1978. Oak Creek Canyon and the red rock country of Arizona. Stillwater Canyon Press, Flagstaff. 142 pp.

Akers, J.P. 1962. Relation of faulting to the occurrence of ground water in the Flagstaff area, Arizona. U.S. Geological Survey Professional Paper 450-B: B97-B100.

Arizona Daily Star. 1944. Story is told of Lake Mary. Tucson, Arizona, January 1, p. 8.

Arizona Daily Sun. 1979. Lake Mary filled up in 1905. Reprint of March 11, 1905 article, 75th Anniversary Edition, Flagstaff, Arizona. May 3, Sect. E:6.

Arizona Heritage. 1979. Heritage conservation section of Arizona state parks board. Vol. 9(2):1-5.

Arnberger, L.P., 1947. Flowering plants and ferns of Walnut Canyon. Museum of Northern Arizona, Flagstaff. Plateau 20:29-36.

Baldwin, A.R. 1987. Walnut Canyon archeological survey: 1987 results. National Park Service. Manuscript on file at the Western Archeological and Conservation Center, Tucson, Arizona.

Baldwin, A.R. and J.M. Bremer. 1986. Walnut Canyon National Monument: An archeological survey, archeological investigations in the Walnut Canyon drainage, North Central Arizona. Western Archeological and Conservation Center, National Park Service, U.S. Department of the Interior, Publications in Anthropology No. 39.

Barnes, W. C. 1935. Arizona place names. The University of Arizona General Bulletin No. 2, The University of Arizona, Tucson. 503 pp. (Reprint, W.C. Barnes and B. H. Granger, 1960, The University of Arizona Press, Tucson. 519 pp.).

Bell, D.T. 1974. Studies on the ecology of a streamside forest: Composition and distribution of vegetation beneath the tree canopy. Bull. Torr. Bot. Club, 101:14-20.

Bemer, S. 1990. Stream survey report 1990. U.S. Department of Agriculture, Forest Service, Coconino National Forest and Arizona Game and Fish Department, Region II. Unnumbered manuscript.

Betancourt, J.L., T.R. Van Devender, and P.S. Martin. 1990. Packrat middens: the last 40,000 years of biotic change. The University of Arizona Press, Tucson, Arizona. 467 pp.

Blee, J.W.H. 1988. Determination of evaporation and seepage losses, Upper Lake Mary near Flagstaff, Arizona. U.S. Geological Survey Water-Resources Investigations Report 87-4250, Tucson, Arizona.

Bonham, C.D. 1989. Measurements for terrestrial vegetation. Wiley Interscience, J. Wiley and Sons, N.Y. 338 pp.

Bremer, J.M. 1988. Settlement and land use in the Walnut Canyon drainage of north central Arizona during the 12th and 13th centuries. Northern Arizona University, Flagstaff, Arizona, unpublished masters thesis.

Bremer, J.M. 1989. Walnut Canyon settlement and land use. Arizona Archaeological Society, Phoenix, Arizona. The Arizona Archaeologist, No. 23.

Brian, N.J. 1992. Historical view of water flow and riparian vegetation at Walnut Canyon National Monument, Arizona. Cooperative National Park Resources Studies Unit, Technical Report NPS/WRUA/NRTR-92/44, Tucson, Arizona. 39 pp.

Broadfoot, W.M. 1967. Shallow-water impoundment increases soil moisture and growth of hardwoods. Soil Sci. Soc. Am. Proc. 31:562-564.

Brown, D.E., (editor) 1982. Biotic communities of the American Southwest - United States and Mexico. Desert Plants. Special Issue. 4(1-4):1-342.

Burton, J.D. 1972. Prolonged flooding inhibits growth of loblolly pine seedlings. USDA For Ser. Res. Note S0:124.

Campbell , C.J. and W. Greene. 1968. Perpetual succession of stream-channel vegetation in a semiarid region. Journal of the Arizona Academy of Science 5:89-98.

Cheremisinoff, N.P. and P.N. Cheremisinoff. 1980. Unit conversions and formulas manual. Butterworth Publishers, Boston, Massachusetts. 171 pp.

Clark, A.B. 1968. Vegetation on archaeological sites compared with non-site locations at Walnut Canyon, Flagstaff, Arizona. Plateau 40(3):77-90.

Coconino Sun. 1926. Souvenir of the dedication of the new half million dollar community water system, Flagstaff, Arizona.

Colton, H.S. 1932. Walnut Canyon National Monument. Museum of Northern Arizona, Flagstaff, Arizona. Museum Notes 4:1-6.

Cook, E. R. and K. Peters. 1981. The smoothing spine: a new approach to standardizing forest interior tree-ring width series for dendroclimatic studies. Tree-Ring Bulletin, Vol. 41:45-53.

Daubenmire, R. 1968. Plant communities: a textbook of plant synecology. Harper and Row, New York. 300 pp.

Dawdy, D.R. and N.C. Matalas. 1964. Statistical and probability analysis of hydrologic data Part III. Analysis of variance, covariance, and time series. *in* V.T. Chow (editor), Handbook of Applied Hydrology, McGraw-Hill, New York, pp. 8-68 to 8-90.

Davis, J.C. 1986. Statistics and data analysis in geology. John Wiley & Sons, New York, 646 pp.

Dean, J.S., R.C. Euler, G.J. Gumerman, F. Plog, R.H. Hevly, and T.N.V. Karlstrom. 1985. Human behavior, demography, and paleoenvironment on the Colorado Plateaus. American Antiquity, 50(3):537-554.

Despain, Del W., and J. Mosley. 1990. Fire history and stand structure of a pinyon-juniper woodland at Walnut Canyon National Monument, Arizona. Report to USDI, National Park Service, Southern Arizona Group Office, Phoenix, Arizona. 28 pp.

Douglass, A.E. 1941. Cross dating in dendrochronology. Journal of Forestry 39:825-831.

Downum, C.E., C.L. Harper, and R. Boston. 1995. Walnut Canyon and water: capture, storage, and use of water during the Sinagua period of occupation, ca. A.D. 100-1300. Northern Arizona University Archeological Draft Report No. 1125. Southwest Parks and Monuments Association Grant No. WACA FY93. 30 pp.

Eagleman, J.R. 1976. The visualization of climate. Lexington Books, Lexington, Massachusetts. 223 pp.

Ellis, J.L. 1973. Pool survey, Walnut Canyon. Manuscript on file at Walnut Canyon National Monument library, Flagstaff, Arizona. 5 pp.

Elmore, F.H. 1976. Trees and shrubs of the Southwest uplands. Southwest Parks and Monuments Association, Popular Series No. 19. 214 pp.

Euler, R.C. 1962. Archaeological survey of the south rim of Walnut Canyon National Monument, Arizona. Arizona State College Archaeological Survey. Manuscript, Walnut Canyon National Monument, National Park Service, Flagstaff, Arizona.

Euler, R.C. 1964. An archaeological survey of the south rim of Walnut Canyon National Monument, Arizona. Arizona State College Anthropological Papers No. 1, Flagstaff, Arizona.

Euler, R.C. and A.P. Olson. 1965. Split-twig figures from northern Arizona; new radiocarbon dates. Science 148:368-369.

Foreman, G. (ed. and annotator). 1941. Pathfinder in the Southwest: the itinerary of Lieutenant A.W. Whipple during his explorations for a railway route from Ft. Smith to Los Angeles

in the years 1953 and 1954. University of Oklahoma Press, Norman, Oklahoma, p. 164-167.

Fritts, H.C. 1976. Tree-rings and climate. Academic Press, London.

Gauch, H.G. 1982. Multivariate analysis in community ecology. Cambridge University Press, Cambridge.

Gilman, P.A. 1976. Walnut Canyon National Monument: An archeological overview. Western Archeological Center, National Park Service, Tucson, Arizona.

Greater, R. K. 1935. Walnut Canyon bird list. Southwestern Mon. Mo. Rept. (Sept.), Supp.: 136.

Haldeman, J.R. and R.B. Clark. 1969. Walnut Canyon: an example of relationships between birds and plant communities. Museum of Northern Arizona, Flagstaff, Arizona. Plateau 41(4):164-177.

Harper, K.T., S.C. Sanderson and E.D. McArthur. 1992. Riparian ecology in Zion National Park Pages 32-42 *in* Clary, W.P., E.D. McArthur, D. Bedunah and C.L. Wambolt (eds.) Proceedings--Symposium on Ecology and Management of Riparian Shrub Communites. U.S.D.A Forest Service, Intermountain Research Station General Technical Report INT-289.

Harshbarger & Associates. 1972. Water resources report, City of Flagstaff, Arizona. John Carollo Engineers. Report on file at the Lake Mary Water Treatment Plant, Flagstaff, Arizona.

Harshbarger & Associates. 1977. Hydrological and geophysical report, Lake Mary Area, City of Flagstaff, Arizona. Prepared for the City Council, Flagstaff, Arizona, Hon. Robert L. Moody, Mayor. Harshbarger and Assn., Tucson, Arizona. Section 4, 86 pp.

Hastings, J.M. and R.M. Turner. 1965. The changing mile: An ecological study of vegetation change with time in the Lower Mile of an arid and semiarid region. The University of Arizona Press, Tucson, Arizona. 317 pp.

Henkle, W.R. 1976. Geology and engineering geology of eastern Flagstaff, Coconino County, Arizona. Northern Arizona University, Flagstaff, Arizona, unpublished master's thesis, 123 pp.

Hill, G.W., T.A. Hales and B.N Aldridge. 1988. Flood hydrology near Flagstaff, Arizona., U. S. Geological Survey-Water Resources Investigation Report 87-4210. 31 pp.

Hill, M.O. 1979a. TWINSPAN. A FORTRAN program for arranging multivariate data in an ordered two-way table by classification of the individuals and attributes. Microcomputer Power, Ithaca, New York. 60 pp.

Hill, M.O. 1979b. DECORANA. A FORTRAN program for detrended correspondence analysis and reciprocal averaging. Microcomputer Power, Ithaca, New York. 36 pp.

Hoffmeister, D.F. and S.W. Carothers 1969. Mammals of Flagstaff, Arizona. Museum of Northern Arizona, Flagstaff, Arizona. Plateau 41(4):184-188.

Holmes, R.L. 1983. Computer-assisted quality control in tree-ring dating and measurement. Tree-Ring Bulletin 43:69-78.

Hughes, F.E. 1965. Tension wood: A review of literature. Forestry Abstracts 16(1)2-9 and 26(2):179-186.

Hupp, C.R. 1992. Riparian vegetation recovery patterns following stream channelization: a geomorphic perspective. Ecology 73:1209-1226.

Jenkins, P., F. Reichenbacher, K. Johnson, and A. Gondor. 1991. Vegetation inventory, classification and monitoring at Walnut Canyon National Monument. Report to USDI, National Park Service, Southern Arizona Group Office, Tucson, Arizona. 71 pp. + 2 maps.

Johnson, M.B. 1993. Woody legumes in southwest desert landscapes. Desert Plants 10(4):147-170.

Johnson, R.R. and C.H. Lowe. 1985. On the development of riparian ecology. pp. 112-116 IN R.R. Johnson, C.D. Ziebell, D.R. Patton, P.F. Ffolliott, and R.H. Hamre, tech. coords. Riparian ecosystems and their management: reconciling conflicting uses. First North American riparian conference. USDA For. Serv. Gen. Tech. Rep. RM-120.

Joyce, J. F. 1974. A taxonomic and ecological analysis of the flora of Walnut Canyon, Arizona. Masters Thesis, Northern Arizona University, Flagstaff, Arizona. 101 pp. (Species list from the thesis also published by Southwest Parks and Monuments Association, Tucson, Arizona in 1985 as a flyer.)

Joyce, J.F. 1976. Vegetation analysis of Walnut Canyon, Arizona. Journal Arizona Academy of Science 11:127-133.

Karr, J.R., and I.J. Schlosser. 1978. Water resources and the land-water interface. Science 201:229-234.

Kennedy, H.E. 1970. Growth of newly planted water tupelo seedlings after flooding and siltation. For. Sci. 16:250-256.

King, D. S. 1941. Monument to vandalism. Arizona Highways 17(10):26-31. Reprint 1945, in Arizona's National Monuments, Southwestern Monuments Association Popular Series No. 2, Santa Fe, New Mexico. 6 pp.

LaBoone, K. 1981. The Arizona Lumber and Timber Company, 1881-1981. Copyright of the Arizona Lumber and Timber.

Lanner, R.M. Trees of the Great Basin, a natural history. University of Nevada Press, Reno. 215 pp.

Larson, G.E. 1993. Aquatic and wetland vascular plants of the Northern Great Plains. General Technical Report RM-238. Fort Collins, Colorado, U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 681 pp.

Little, E.L. Jr. 1976. Southwestern trees: a guide to the native species of New Mexico and Arizona. Agriculture Handbook No. 9, U.S. Department of Agriculture. 109 pp.

Maeglin, R.R. and L.F. Ohmann. 1973. Boxelder (*Acer negundo*): a review and commentary. Bulletin of the Torrey Botanical Club: 100:357-363

Malanson, G.P. 1993. Riparian landscapes. Cambridge University Press, Cambridge. 296 pp.

McAlpine, R.B. 1961. Yellow-poplar seedlings intolerant to flooding. J. For. 59:566-568.

McDougall, W.B. 1973. Seed plants of northern Arizona. The Museum of Northern Arizona, Flagstaff, Arizona. 594 pp.

McGavock, E.H. and L.J. Mann. 1974. Walnut Canyon National Monument, Coconino County, Arizona. U.S. Geological Survey (Flagstaff Sub-district) Memorandum Report.

McGavock, E.H., T.W. Anderson, O. Mooseburner, and L.J. Mann. 1986. Water resources of southern Coconino County, Arizona. Arizona Department of Water Resources, Bulletin 4, U.S. Geological Survey, Tucson, Arizona. 53 pp.

Miller, R.P. 1954. An urban study of Flagstaff and vicinity. Masters Thesis, Northern Arizona University, Flagstaff, Arizona. 113 pp.

Mitsch, W.J. and J.G. Gosselink. 1993. Wetlands. Van Nostrand Reinhold, New York. 722 pp.

Mohler, C.L. 1987. Cornell ecology programs MS-Dos. Microcomp Inc., Ithaca, New York.

Montgomery, E.L. and R.H. Dewitt. 1982. Hydrogeology of sources of municipal water, Flagstaff, Arizona. Arizona Water and Pollution Control Association Spring Meeting, Flagstaff, Arizona.

Mueller-Dombois, D. and H. Ellenberg. 1974. Aims and methods of vegetation ecology. John Wiley & Sons, New York. 547 pp.

Murdock, L. 1994. Analysis of woodrat (*Neotoma*) middens found in Walnut Canyon, Coconino County, Arizona. Masters thesis, Northern Arizona University, Flagstaff, Arizona. 74 pp.9

National Oceanic and Atmospheric Administration. 1989. 1989 local climatological data, annual summary with comparative data, Flagstaff, Arizona. U.S. Department of Commerce, Government Printing Office, Washington, D.C. 6 pp.

National Oceanic and Atmospheric Administration. 1993. Local climatological data, monthly summary for January and February, for Flagstaff, Arizona, National weather service office at Pulliam Airport.

National Park Service. 1992. Draft natural and cultural resources management plan. National Park Service, Southern Arizona Group, Phoenix, Arizona. 19 pp.

Neilsen, R.P. 1986. High resolution climatic analysis and Southwest biogeography. Science, 232:27-32.

Northern Arizona Leader. 1970. Flagstaff, Arizona, Part 2, Section 1, June 25, 7 pp.

Peacock, E.W. 1978. Paleomagnetic and geomagnetic studies in the Lake Mary area, Coconino County, Arizona. Masters Thesis, Northern Arizona University, Flagstaff, Arizona.

Peters K. and E.R. Cook. 1981. The cubic smoothing spline as a digital filter. Lamont-Doherty Geological Observatory of Columbia University. Technical Report #CU-1-81/TRI, 25 pp. + figures.

Phillips, B.G. 1990. Riparian inventory of Walnut Canyon National Monument. Report to Southwest Parks and Monuments Association, Tucson, Arizona. Unpaginated.

Reger, R.D. and Batchelder, G.L. 1971. Late Pleistocene mollusks and a minimum age of Meteor Crater, Arizona. Journal of the Arizona Academy of Science 6:190-195.

Rosgen, D.L. 1985. A stream classification system. Pages 91-95 *in* Riparian ecosystems and their management, reconciling conflicting uses. Proceedings of the First North American Riparian Conference, April 16-18, 1985, Tucson, AZ, GTR-RM120.

Salomonson, M. 1973. The mammals of Walnut Canyon National Monument. The Museum of Northern Arizona, Flagstaff, Arizona. Plateau 46(1):19-24. (Also republished 1985, Southwest Parks and Monuments Association, Tucson, as " A Checklist of Mammals of Walnut Canyon National Monument.)

Samuels, M.L. and J.L. Betancourt. 1982. Modeling the long-term effects of fuelwood harvests on pinyon-juniper woodlands. Environmental Management 6, 505-515.

Schilling, Mark, A. 1980. A vegetational survey of the Volunteer and Sycamore Canyon region. Masters Thesis, Northern Arizona University, Flagstaff, Arizona. 97 pp.

Schroeder, A.H. 1977. Of men and volcanoes: the Sinagua of northern Arizona. Southwest Parks and Monuments Association. 70 pp.

Schuyler, J.D. 1909. Reservoirs for irrigation, waterpower and domestic water-supply. Second edition, John Wiley & Sons, New York. pp. 284-286.

Sellers, W. D. and R.H. Hill (editors). 1974. Arizona climate 1931-1974. Revised second edition. The University of Arizona Press, Tucson. 503 pp.

Shimer, H.W., and F.H. Shimer. 1910. The lithological section of Walnut Canyon, Arizona, with relation to the cliff-dwellings of this and other regions of northwestern Arizona. American Anthropologist 12 (New Series): 237-249.

Sigafoos, R.S. 1964. Botanical evidence of floods and floodplain deposition. U.S. Geological Survey Professional Paper 485A.

Smith, J.B. 1991. A guide to the Beale wagon road through the Coconino National Forest. Tales of the Beale Rock Publishing Company, Flagstaff, Arizona. 60 pp.

Smith, M. L. 1983. The Riordan brothers and the development of Northern Arizona. Masters Thesis, Northern Arizona University, Flagstaff, Arizona. 114 pp.

Southwest Parks and Monuments Association. 1971. Island Trail Walnut Canyon National Monument, Arizona. Southwestern Parks and Monuments Association, Globe, Arizona. 16 pp.

Spangle, P.F. 1953. A revised checklist of the flora of Walnut Canyon National Monument. Museum of Northern Arizona, Flagstaff, Arizona. Plateau 26:86-88.

Spangle, P. and E. Spangle. 1953. Birds of Walnut Canyon. Southwest Parks and Monuments Association, Phoenix, Arizona. 13 pp.

Stein, P.H. 1986. Historical Resources. Walnut Canyon. *in* A.R. Baldwin and J.M. Bremer, editors. Walnut Canyon National Monument: An Archeological Survey. Western Archeological Conservation Center, National Park Service, Tucson, Arizona. Publications in Anthropology No. 39.

Stokes, M.A. and T. L. Smiley. 1968. An introduction to tree-ring dating. The University of Chicago Press, Chicago, Illinois. 73 pp.

Swanson, F.J., S.V. Gregory, J.R. Sedell, and A.G. Campbell. 1982. Land-water interactions: the riparian zone. pp. 267-291 In: R.L. Edmonds, ed. Analysis of coniferous forest ecosystems in the western United States. US/IBP Synthesis Ser. 14, Hutchinson Ross Pubs.. Co., Stroudsburg, Pa.

Swetnam, T.W., W. Wright, A. Caprio, P. Brown, C. Baisan. 1990. Fire scar dates from Walnut Canyon National Monument, Arizona. Report to USDI, National Park Service, Southern Arizona Group Office, Phoenix, Arizona. 16 pp.

Teskey, R.O. and T.M. Hinckley. 1977. Impact of water level changes on woody riparian and wetland communities. Vol. 1: Plant and soil responses. Fish and Wildlife Service, Biological Services Program, OBS-77/58, U.S. Government Printing Office. 30 pp.

Thornthwaite, C.W. and J.R. Mather. 1957. Instructions and tables for computing potential evapotranspiration and water balance. Publications in Climatology 10(3):185-311.

Tiner, R.W., Jr. 1984. Wetlands of the United States: current status and recent trends. U.S. Gov. Printing Off., Washington, D.C., 59 pp.

U.S. Department of Agriculture, Forest Service. 1989. Riparian area survey and evaluation system (RASES). Revised Draft dated 5/89. 91 pp.

U.S. Department of Interior. 1985. Statement for management Walnut Canyon National Monument. April 1985 (dated 1986 on cover sheet). 15 pp. + appendices.

U.S. Geological Survey. 1962. Topographic map. Flagstaff East, Arizona quadrangle, Coconino County, 7.5 min. series. U.S. Government Printing Office, Washington, D.C.

U.S. Geological Survey. 1968. Topographic map. Winona, Arizona quadrangle, Coconino County, 7.5 min. series. U.S. Government Printing Office, Washington, D.C.

U.S. Geological Survey. 1993. Floods in Arizona, January 1993. Water Fact Sheet, U.S. Geological Survey, Open-File Report 93-54, 1 pp.

Vines, R.A. 1960. Trees, shrubs and woody vines of the Southwest. University of Texas Press, Austin, Texas. 1104 pp.

Walnut Canyon National Monument. 1976. National Park Service, Department of Interior. Natural and cultural resource management plan and environmental assessment, Walnut Canyon National Monument, Arizona.

Warren, P.L., K.L. Reichhardt, D.A. Mouat, B.T. Brown, and R.R. Johnson. 1982. Vegetation of Grand Canyon National Park. USDI, National Park Service, CPSU Tech. Rep. No. 9, University of Arizona, Tucson, Arizona. 140 pp.

Webb, R.H. and J. L. Betancourt. 1992. Climatic variability and flood frequency of the Santa Cruz River, Pima County, Arizona. U.S. Geological Survey Water-supply Paper 2379. 40 pp.

Weber, S. 1981. A palynological interpretation of the Sinagua and their changing environment. Masters Thesis, Northern Arizona University, Flagstaff, Arizona.

Welsh. S.L., N.D. Atwood, L.C. Higgins, S. Goodrich. 1987. A Utah flora. Great Basin Naturalist Memoirs No. 9. Brigham Young University, Provo Utah. 894 pp.

Westing, A.H. 1968. Formation and function of compression wood in gymnosperms. II. Botanical Review 34:51-78.

Yelenosky, G. 1964. Tolerance of trees to deficiencies of soil aeration. Int. Shade Tree Con. Proc. 40:127-148.

Appendix I. Unit conversion chart (from Cheremisinoff and Cheremisinoff 1980).

To Convert From	Multiply By	To Obtain
	Length	
millimeter (mm)	0.03937	inch (in)
centimeter (cm)	0.3937	inch (in)
meter (m)	3.281	feet (ft)
kilometer (km)	0.6214	mile (mi)
	Area	
square meter (m^2)	10.76	square feet (ft^2)
square kilometer (km^2)	0.3861	square mile (mi^2)
hectares (ha)	2.5	acre (ac)
	Volume	
cubic feet per second (cfs)	0.02832	cubic meter per second (m^3)
acre-feet per year (ac-ft/yr)	0.001233	cubic hectometer per year (hm^3/yr)
gallon (gal)	3.785	liter (l)
gallon (gal)	0.003785	cubic meter (m^3)
gal per minute (gal/min)	2.228×10^{-3}	cubic feet per second (cfs)
	Temperature	
degree Celsius (°C)	1.8 temp °C+32	degree Fahrenheit (°F)

Appendix 2. Alphabetical list of common names of plant species used in the text, their scientific binomial equivalents, and scientific names.

Common Name	Scientific Binomial	Scientific Name
Apache plume	FAPA	*Fallugia paradoxa*
Arizona grape	VIAR	*Vitus arizonica*
Arizona rose	ROAR	*Rosa arizonica*
Arizona walnut	JUMA	*Juglans major*
Aspen	POTR	*Populus tremuloides*
Bee balm	MOME	*Monarda menthaefolia*
Big-tooth maple	ACGR	*Acer grandidentatum*
Blue grama	BOGR	*Bouteloua gracilis*
Bonpland willow	SABO	*Salix bonplandiana*
Boxelder	ACNE	*Acer negundo*
Buckwheat	ERSP	*Erigonum sp.*
Canada wild rye	ELCA	*Elymus canadensis*
Cat-tail	TYLA	*Typha latifolia*
Clematis	CLLI	*Clematis ligusticifolia*
Cliffrose	COST	*Cowania stansburiana*
Desert olive	FOPU	*Forestiera pubescens*
Dogbane	APCA	*Apocynum cannabinum*
Douglas fir	PSME	*Pseudotsuga menziesii*
Downy chess	BRTE	*Bromus tectorum*
Dragon sage	ARDR	*Artemisia dracunculus*
False solomon seal	SMRA	*Smilicina racemosa*
Fernbush	CHMI	*Chamaebatiaria millefolium*
Four-wing saltbush	ATCA	*Atriplex canescens*
Fremont barberry	BEFR	*Berberis fremontii*
Gambel oak	QUGA	*Quercus gambelii*
Goldenrod	SOSP	*Solidago sparsiflora*
Hop	HUAM	*Humulus americana*
Little bluestem	SCSC	*Schizachyrium scoparium*
Magellans phacelia	PHMA	*Phacelia magellanica*
Meadow rue	THRE	*Thalictrum fendleri*
Milk vetch	ASTE	*Astragalus tephrodes*
Missouri iris	IRMI	*Iris missouriensis*
Motherwort	LECA	*Leonurus cardiaca*
Mutton grass	POFE	*Poa fendleriana*
Narrowleaf cottonwood	POAN	*Populus angustifolia*
Narrowleaf hoptree	PTAN	*Ptelea angustifolia*
New Mexico locust	RONE	*Robinia neomexicana*
One-seed juniper	JUMO	*Juniperus monosperma*
Peach-leaf willow	SAAM	*Salix amygdaloides*
Poison ivy	TORA	*Toxicodendron radicans*
Ponderosa pine	PIPO	*Pinus ponderosa*

Appendix 2. Continued

Common Name	Scientific Binomial	Scientific Name
Rabbitbrush	CHSP	*Chrysothamnus* sp.
Red osier dogwood	COST	*Cornus stolonifera*
Richardsons brome	BRRI	*Bromus richardsonii*
Rocky Mountain juniper	JUSC	*Juniperus scopulorum*
Russian thistle	SAIB	*Salsoa iberica*
Sage	ARSP	*Artemisia* sp.
Scouler's willow	SASC	*Salix scouleriana*
Sedge	CAOC	*Carex occidentalis*
Service berry	AMUT	*Amelanchier utahensis*
Sideoats grama	BOCU	*Bouteloua curtipendula*
Snakeweed	GUSP	*Gutierrezia* sp.
Snowberry	SYPH	*Symphoricarpos parishii*
Squaw bush	RHTR	*Rhus trilobata*
Thicket creeper	PAVI	*Parthenocissus vitacea*
Wax currant	RIAU	*Ribes aureum*
Wheatgrass	AGSM	*Agropyron smithii*
Willows	SASP	*Salix* spp.
Wormwood	ARLU	*Artemisia ludoviciana*
Yellow pond lily	NULU	*Nuphar luteum* ssp. *polycephalum*
Yucca	YUSP	*Yucca* sp.

Appendix III. A portion of the 44 year, Upper Lake Mary Weekly hydrological database used in this study.

Yr	Mo.	Day	Lake Depth (ft)	Prec. (in)	Surface Water Diversion (gal x 10^3)	Lake Volume (gal)[1]	Estimated Seepage[2] (gal)	Gross Vol (gal)	Diff Vol (gal)	Estimated Inflow Vol (gal)	Estimated Inflow Vol (cu ft)	Estimated Inflow Vol (ac-ft)	Estimated Inflow Rate (cfs) Over one Week	Lower Lake Mary Depth (ft)
93	1	7	31.2	2.49	37,356	3,156,000,000	30,274,749	3,223,630,749	742,327,127	742,327,127	99,249,137	2,278.12	164.1	6
93	1	14	38.4	3.05	29,488	5,063,000,000	47,770,720	5,140,258,720	1,916,627,971	1,916,627,971	256,253,160	5,881.92	423.7	11
93	1	21	38.8	2.62	33,165	5,177,000,000	48,882,708	5,259,047,708	118,788,988	118,788,988	15,882,088	364.55	26.3	15
93	1	28	38.5	---	36,713	5,091,000,000	48,047,290	5,175,760,290	-83,287,419	no inflow	no flow	no flow	no flow	15
93	2	4	38.5	1.29	23,756	5,091,000,000	48,047,290	5,162,803,290	-12,957,000	no inflow	no flow	no flow	no flow	15
93	2	11	38.8	2.72	11,410	5,177,000,000	48,882,708	5,237,292,708	74,489,419	74,489,419	9,959,235	228.60	16.5	18
93	2	18	38.6	1.29	18,390	5,119,000,000	48,324,810	5,185,714,810	-51,577,898	no inflow	no flow	no flow	no flow	18
93	2	25	38.7	5.48	11,007	5,148,000,000	48,603,283	5,207,610,283	21,895,472	21,895,472	2,927,425	67.19	4.8	24
93	3	4	38.7	0.59	6,457	5,119,000,000	48,603,283	5,174,060,283	-33,550,000	no inflow	no flow	no flow	no flow	22
93	3	11	39.0	0.01	18,127	5,119,000,000	49,444,424	5,186,571,424	12,511,142	12,511,142	1,672,740	38.40	2.8	23
93	3	18	38.6	0.16	17,839	5,119,000,000	48,324,810	5,185,163,810	-1,407,614	no inflow	no flow	no flow	no flow	23
93	3	25	38.7	0.02	24,263	5,119,000,000	48,603,283	5,191,866,283	6,702,472	6,702,472	896,121	20.57	1.5	23
93	4	1	38.7	1.13	29,958	5,119,000,000	48,603,283	5,197,561,283	5,695,000	5,695,000	761,422	17.48	1.3	23
93	4	8	38.6	0.26	28,674	5,019,000,000	48,324,810	5,095,998,810	-101,562,472	no inflow	no flow	no flow	no flow	22
93	4	15	38.5	---	30,261	5,090,000,000	48,047,290	5,168,308,290	72,309,480	72,309,480	9,667,777	221.91	16.0	---
93	4	22	38.1	---	36,013	4,979,000,000	46,946,702	5,061,959,702	-106,348,587	no inflow	no flow	no flow	no flow	21
93	4	29	37.8	---	34,216	4,979,000,000	46,131,196	5,059,347,196	-2,612,507	no inflow	no flow	no flow	no flow	21
93	5	6	37.5	0.03	19,304	4,811,000,000	45,324,167	4,875,628,167	-183,719,029	no inflow	no flow	no flow	no flow	20
93	5	13	37.2	0.06	32,989	4,699,000,000	44,525,580	4,776,514,580	-99,113,586	no inflow	no flow	no flow	no flow	20
93	5	20	36.9	0.33	24,720	4,643,000,000	43,735,404	4,711,455,404	-65,059,177	no inflow	no flow	no flow	no flow	20
93	5	27	36.7	1.43	31,733	4,587,000,000	43,213,275	4,661,946,275	-49,509,129	no inflow	no flow	no flow	no flow	---

1 The city of Flagstaff has a lake depth - volume relationship which is used to estimate the lake volume

2 Seepage estimated from a lake stage - seepage relationship obtained from the City of Flagstaff, water treatment plant. Seepage values were regressed against lake depth using a cubic polynomial regression; adjusted $R^2 = 0.99976$; $F = 24909.39$; $p<0.0001$.

Appendix III. (Continued)

CALCULATION OF GROSS VOLUME AND ESTIMATED INFLOW

In order to illustrate the method of calculating estimated inflow to Lake Mary, we refer to the shaded portion of the partial Upper Lake Mary Database above. On 93-1-14, the depth of Upper Lake Mary was just below maximum at 38.4 ft. Surface water diversion to the city of Flagstaff was 29,488,000 and lake volume was 5,063,000,000 gal. Estimated seepage was 47,770,720 gal. Therefore the gross volume was 29,488,000 plus 5,063,000,000 plus 47,770,720 which equals 5,140,258,720 gallons. The previous week's gross volume was 3,223,630,749 gal so there is an increase in volume equal to 1,916,627,971 gal or 256,253,160 cu ft which is approximately 5881.92 ac-ft. By averaging this volume over the week where it occurred (i.e., 7 day x 24 hr/day x 60 min/hr x 60 sec/min = 604,800 seconds), the mean inflow into Upper Lake Mary over this time period is estimated to be 423.7 cu ft/sec. Similarly, there is also an increase in volume between 93-1-21 and 93-1-14 but it is smaller, only 118,788,988 gal which converts into a mean inflow estimate of 26.3 cfs. Upper Lake Mary's depth on 93-1-21 was 38.8 ft (above maximum of 38.5 ft) so it was spilling. Notice that the depth of Lower Lake Mary is increasing. It is well below its maximum depth (20.7 ft) at this time so it is in the process of filling. The difference in gross volumes between 93-1-28 and 93-1-21 is negative. That is, there was no inflow.

By accumulating inflow estimates over the 44 year weekly database in the above manner, it was possible to construct a record of probable inflows into the drainage. Separation into discrete classes of inflow rates and frequencies was possible by a simple database sort using the estimates of inflow rate (next to last column above) in descending order as the sort key. By resorting the database using the Upper Lake Mary Lake Levels as a secondary key, we get a database arranged in descending order by estimated mean weekly inflow and depth. A record with a maximum depth and an estimated mean weekly inflow greater than zero indicates a spill from Upper Lake Mary.

Note also the record of 93-3-18 where there appears to be no inflow into Upper Lake Mary, yet Lower Lake Mary shows a depth of 23 ft, well above its maximum depth of 20.7 ft and is overflowing.

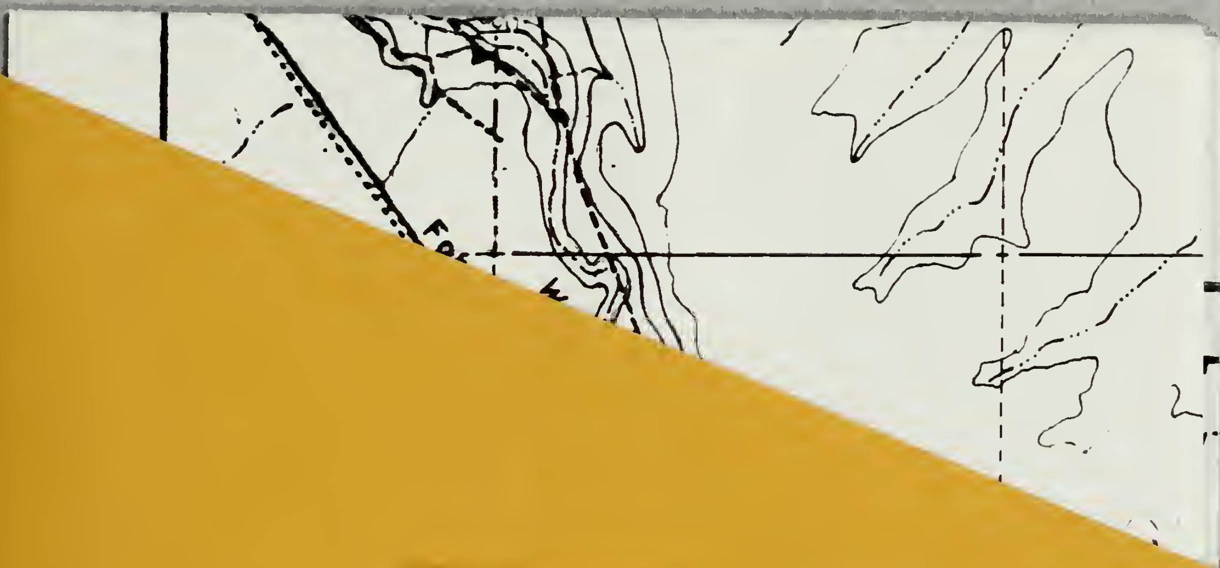
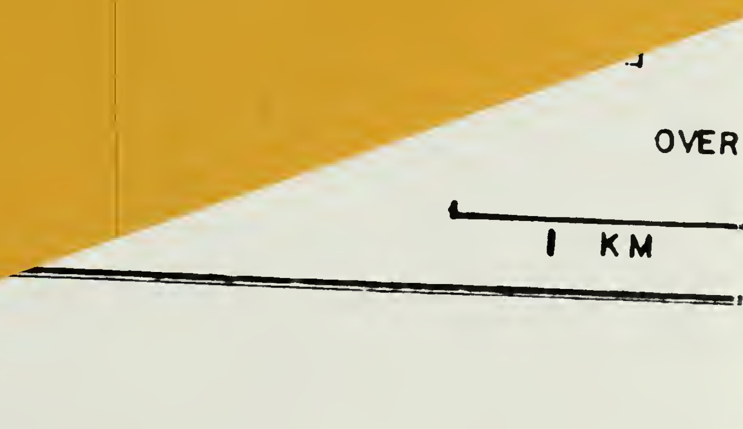


Figure 4.


OVERI
1 KM